US009768361B2

(12) **United States Patent**
Riel et al.

(10) **Patent No.: US 9,768,361 B2**
(45) **Date of Patent: Sep. 19, 2017**

(54) **LIGHT EMITTER AND LIGHT DETECTOR MODULES INCLUDING VERTICAL ALIGNMENT FEATURES**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/903,217**

(22) PCT Filed: **Jul. 22, 2015**

(86) PCT No.: **PCT/SG2015/050225**

§ 371 (c)(1),
(2) Date: **Jan. 6, 2016**

(87) PCT Pub. No.: **WO2016/013978**

PCT Pub. Date: **Jan. 28, 2016**

(65) **Prior Publication Data**

US 2016/0306265 A1 Oct. 20, 2016

Related U.S. Application Data

(60) Provisional application No. 62/028,167, filed on Jul. 23, 2014, provisional application No. 62/044,594,

(Continued)

(51) **Int. Cl.**
H01L 33/48 (2010.01)
G02B 7/02 (2006.01)

(Continued)

(52) **U.S. Cl.**
CPC ***H01L 33/483*** (2013.01); ***G02B 7/003*** (2013.01); ***G02B 7/02*** (2013.01); ***G03B 21/142*** (2013.01);

(Continued)

(58) **Field of Classification Search**
CPC G02B 6/4228; G02B 7/022; G02B 7/025; G02B 27/0025; G02B 6/423;

(Continued)

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,838,689 B1 * 1/2005 Deng G02B 6/4224 250/239
7,223,619 B2 * 5/2007 Wang H01S 5/423 257/E33.072

(Continued)

FOREIGN PATENT DOCUMENTS

JP 2010-066742 3/2010
KR 1020080064335 7/2008

(Continued)

OTHER PUBLICATIONS

Australian Patent Office, International Search Report and Written Opinion, issued by ISA/AU in International Patent Application No. PCT/SG2015/050225 (Nov. 2, 2015).

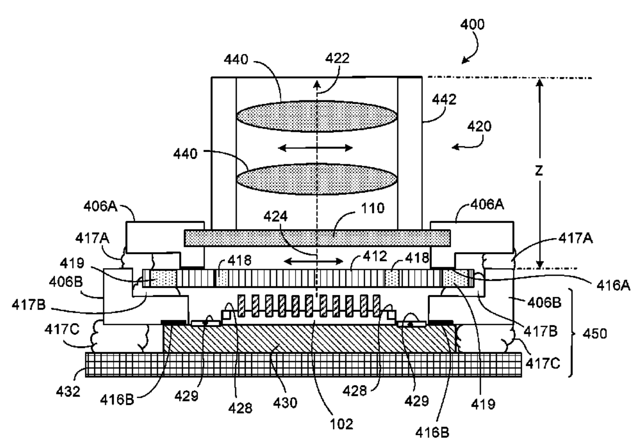
(Continued)

Primary Examiner — Bao-Luan Le
(74) *Attorney, Agent, or Firm* — Fish & Richardson P.C.

(57) **ABSTRACT**

This disclosure describes various modules that can provide ultra-precise and stable packaging for an optoelectronic device such as a light emitter or light detector. The modules include vertical alignment features that can be machined, as needed, during fabrication of the modules, to establish a

(Continued)



precise distance between the optoelectronic device and an optical element or optical assembly disposed over the optoelectronic device.

14 Claims, 21 Drawing Sheets

Related U.S. Application Data

filed on Sep. 2, 2014, provisional application No. 62/150,473, filed on Apr. 21, 2015.

(51) **Int. Cl.**
H01L 33/58 (2010.01)
G02B 7/00 (2006.01)
G03B 21/14 (2006.01)
G03B 21/20 (2006.01)
H01L 27/146 (2006.01)

(52) **U.S. Cl.**
CPC ***G03B 21/2033*** (2013.01); ***H01L 33/58*** (2013.01); *H01L 27/14618* (2013.01); *H01L 2933/0033* (2013.01); *H01L 2933/0058* (2013.01)

(58) **Field of Classification Search**
CPC G02B 6/4232; G02B 7/021; G02B 7/003; G02B 7/02; H01L 33/10; H01L 33/405; H01L 31/0203; H01L 31/0232; H01L 33/105; H01L 27/14618; H01L 2933/0033; H01L 2933/0058; H01L 33/483; H01L 33/58; H01S 5/02288; H01S 5/0226; H01S 5/02268; G03B 21/142; G03B 21/2033
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,029,157 B2* 10/2011 Li F21V 5/048 362/245
8,246,210 B2* 8/2012 Angelini F21L 4/027 362/187
8,979,316 B2* 3/2015 Lee F21V 5/002 362/268
2004/0184155 A1* 9/2004 Kornblit G02B 27/0068 359/619
2004/0264862 A1* 12/2004 Nagano G02B 6/4206 385/39
2005/0052751 A1* 3/2005 Liu G02B 3/0012 359/626
2006/0045410 A1 3/2006 Trott et al.
2006/0083459 A1* 4/2006 Minamio H01L 31/0203 385/14
2006/0180887 A1* 8/2006 Ono H01L 27/14618 257/432
2009/0002853 A1* 1/2009 Yuan G02B 7/021 359/819
2010/0025710 A1* 2/2010 Yamada H01L 27/14618 257/98
2010/0117176 A1* 5/2010 Uekawa H01L 27/14618 257/432
2010/0128350 A1* 5/2010 Findlay G02B 1/118 359/601
2011/0052118 A1* 3/2011 Matsuoka G02B 6/12002 385/14
2011/0267823 A1* 11/2011 Angelini F21L 4/027 362/277
2011/0292271 A1* 12/2011 Lin G02B 13/0085 348/340
2013/0070215 A1* 3/2013 Higo G03B 21/204 353/85
2014/0125849 A1* 5/2014 Heimgartner H01L 27/14625 348/276
2014/0268787 A1* 9/2014 Nozaki H01S 3/005 362/259
2014/0376092 A1* 12/2014 Mor G01B 11/2513 359/569
2016/0133762 A1* 5/2016 Blasco Claret ... H01L 27/14685 257/432

FOREIGN PATENT DOCUMENTS

KR 2010-066742 3/2010
WO WO 2010/052903 5/2010
WO 2010/074743 7/2010
WO 2010/111465 9/2010
WO WO 2010111465 A1 * 9/2010 .... G02B 7/025
WO 2012/022000 2/2012

OTHER PUBLICATIONS

Office Action issued in Korean Application No. 10-2016-7000323, dated Dec. 21, 2016, 15 pages (with English translation).

* cited by examiner

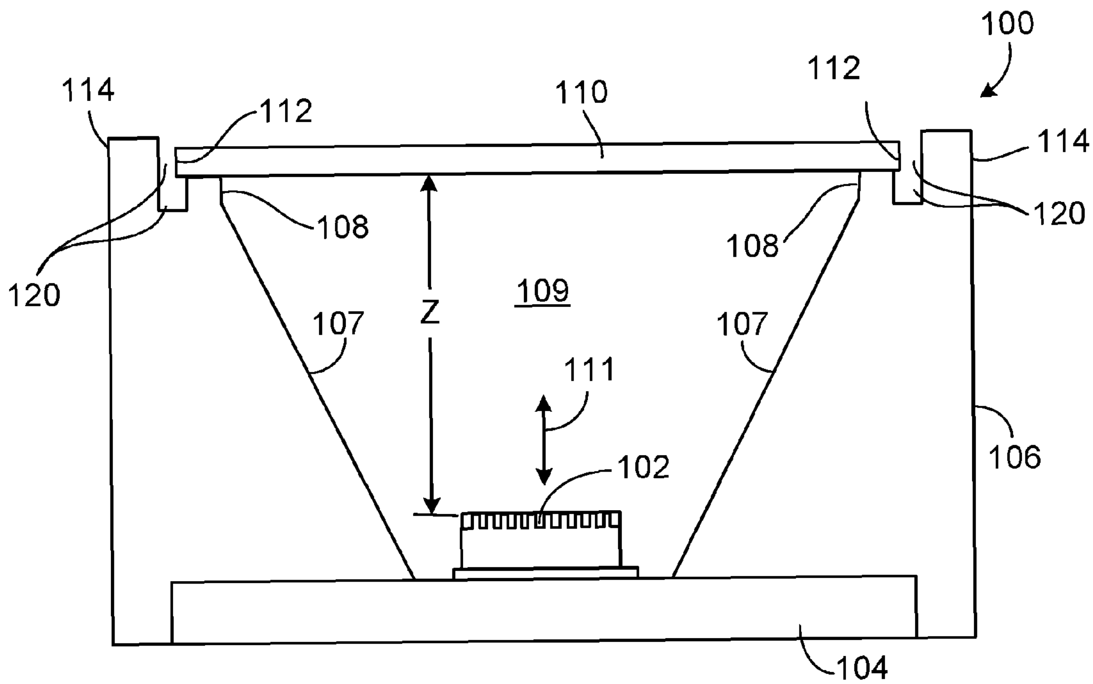

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FIG. 1A

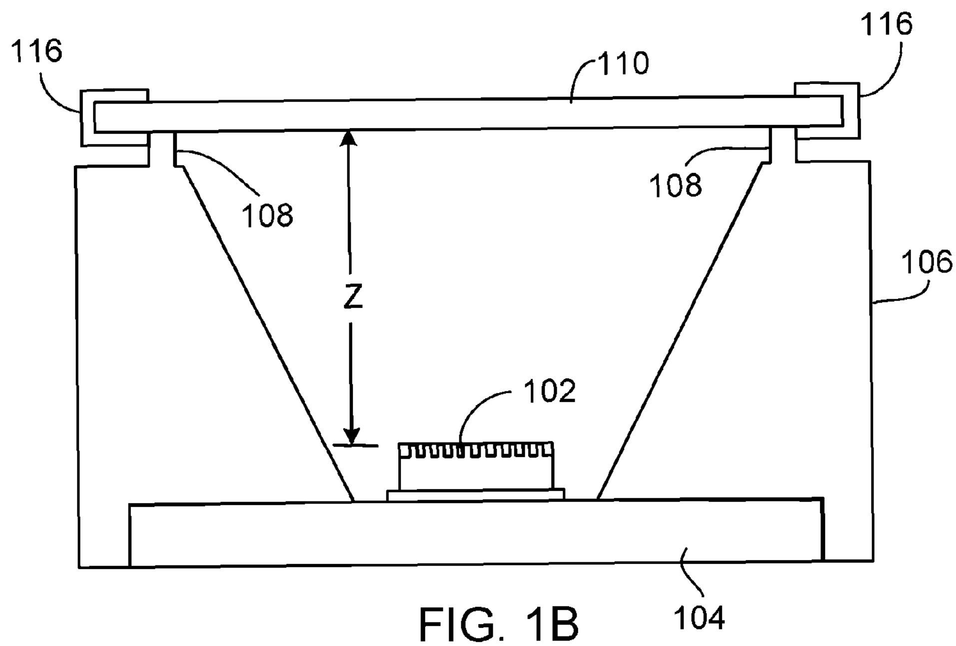
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FIG. 1B

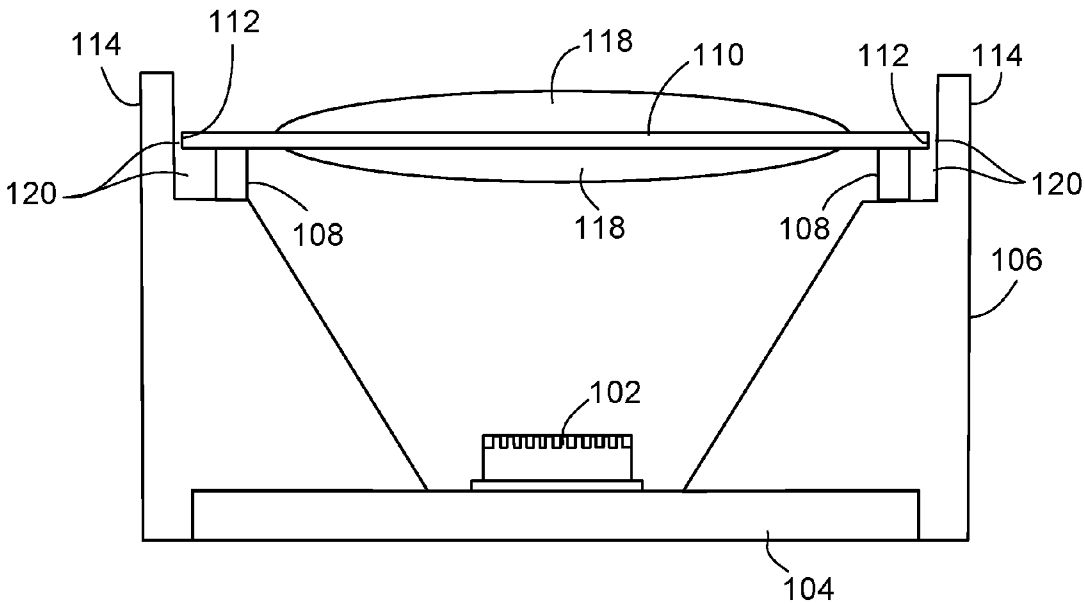

FIG. 1C

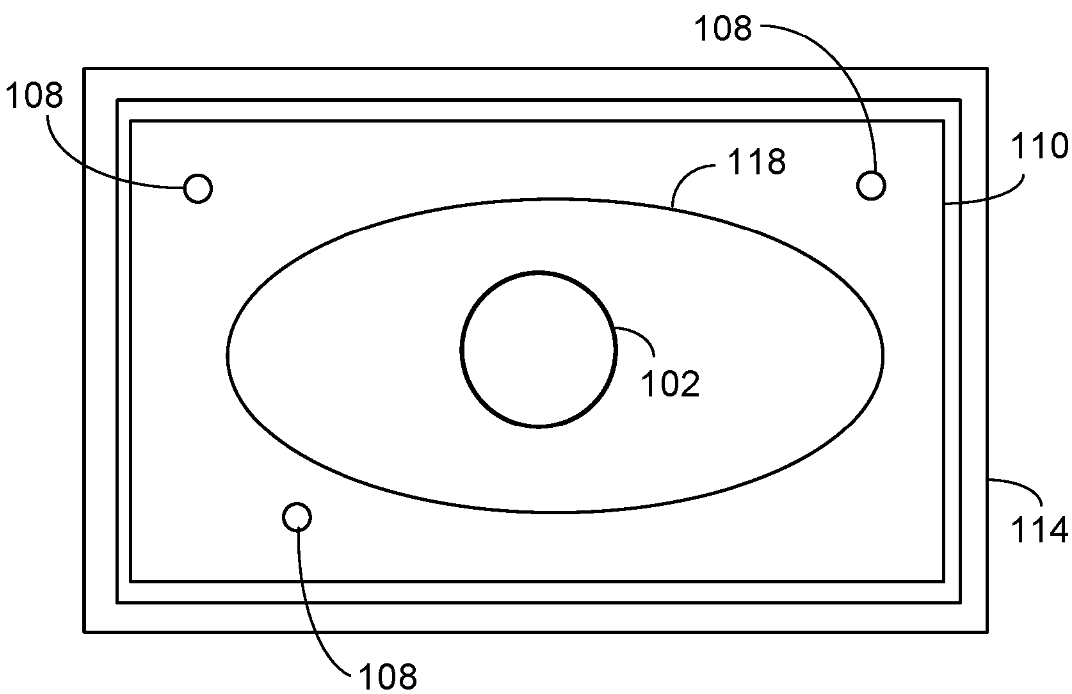

FIG. 2

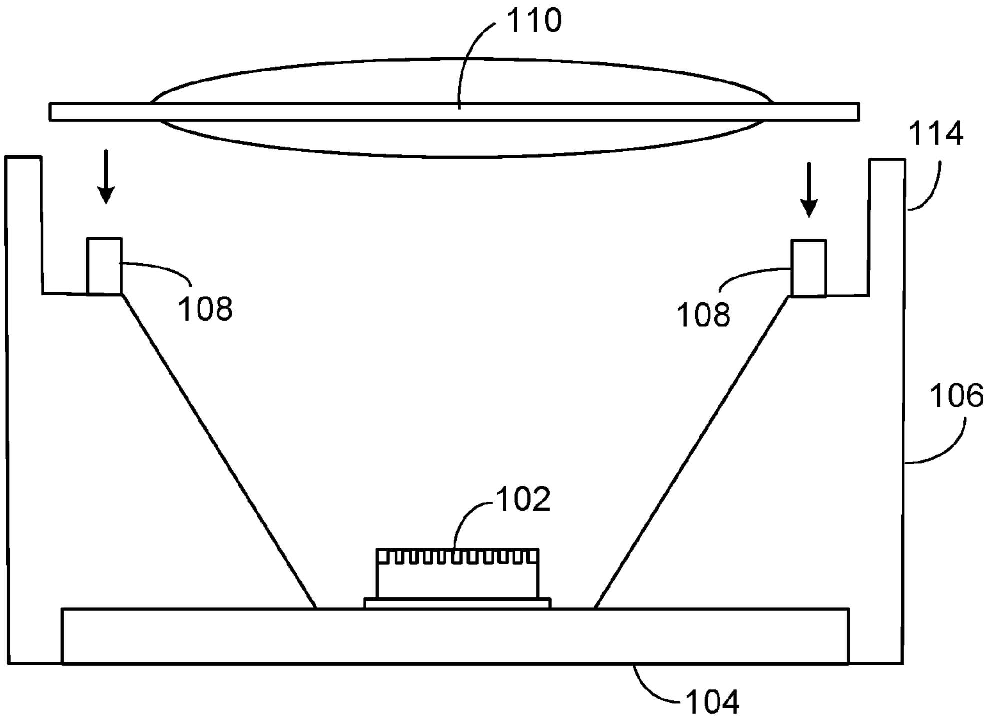

FIG. 3A

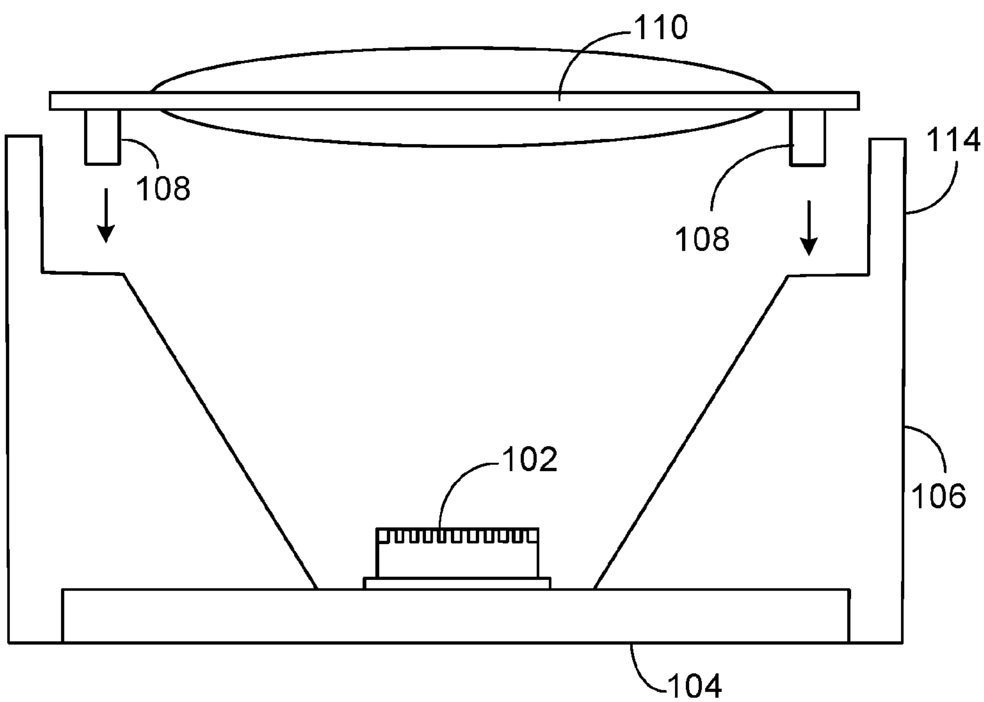

FIG. 3B

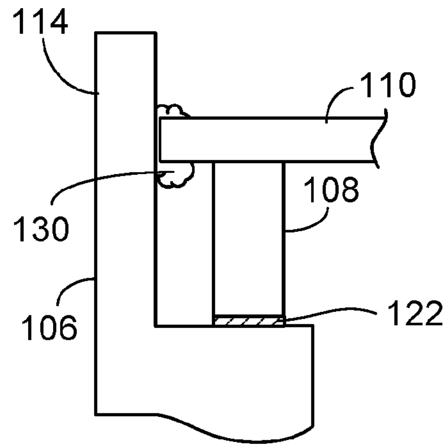

FIG. 4A

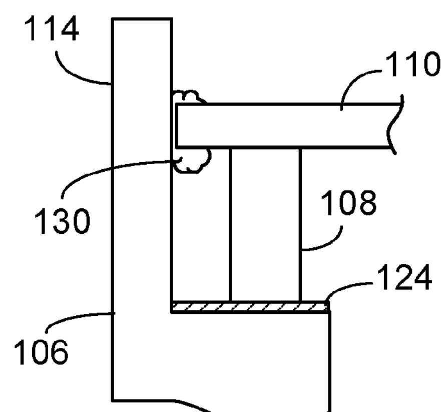

FIG. 4B

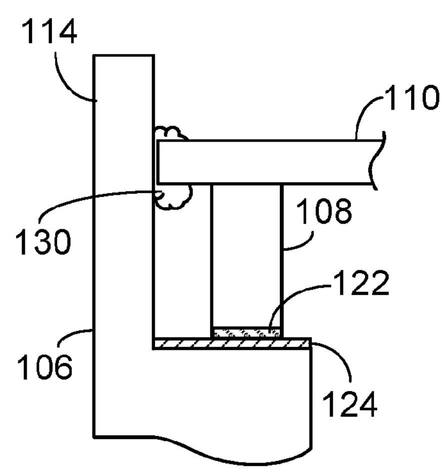

FIG. 4C

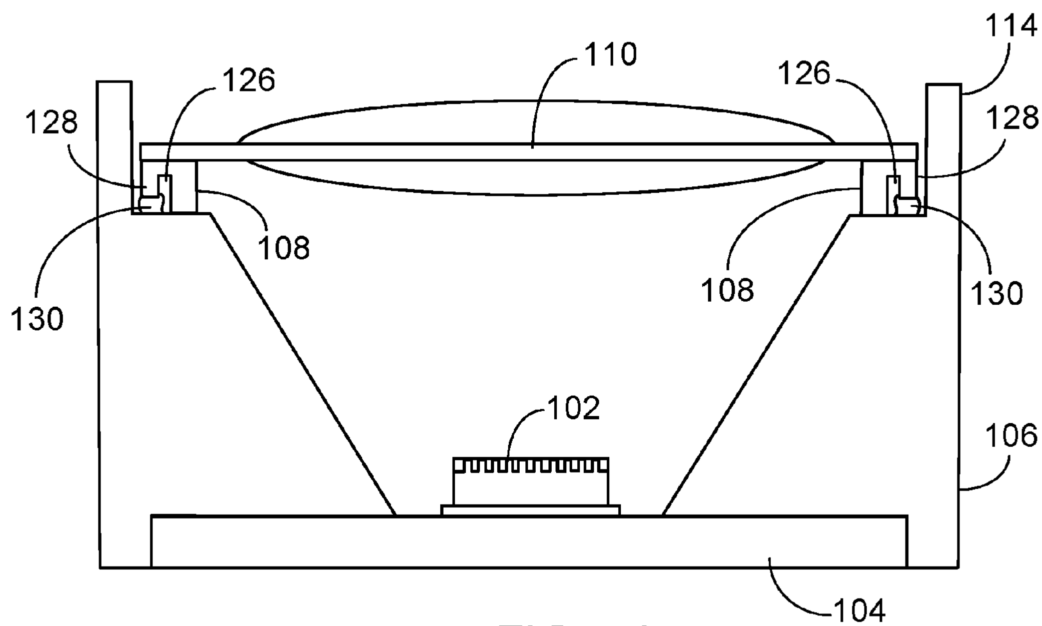
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FIG. 5A

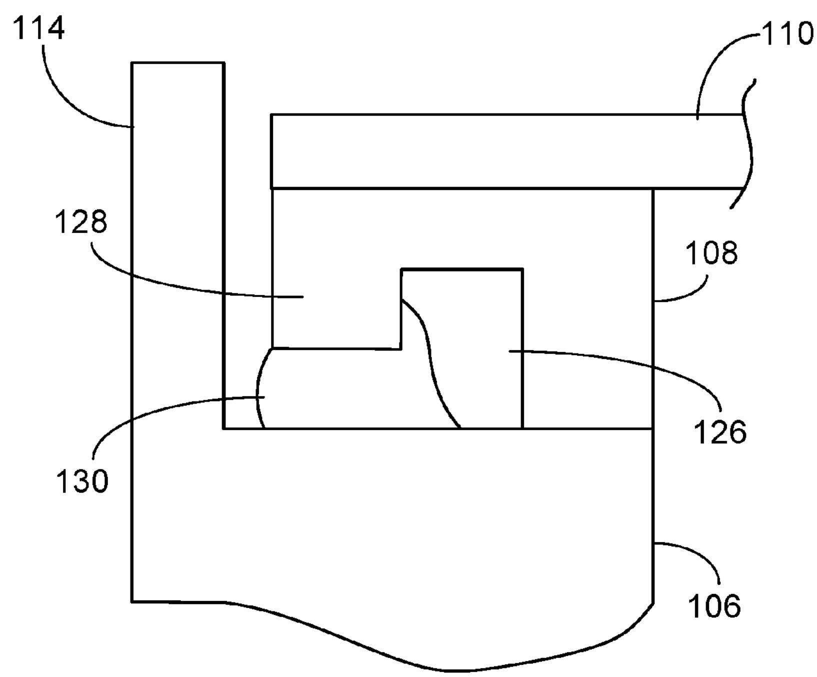
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FIG. 5B

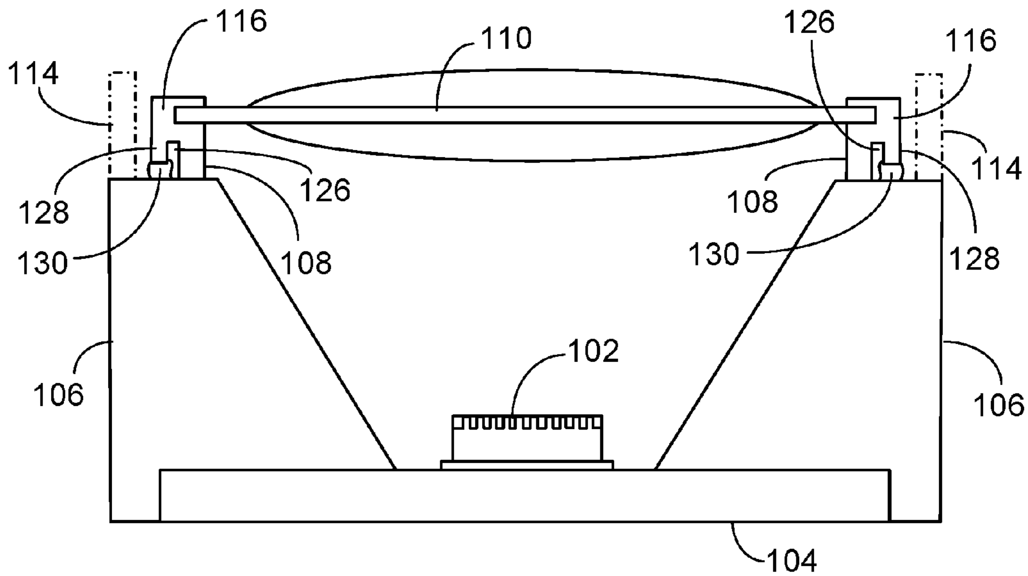
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FIG. 6A

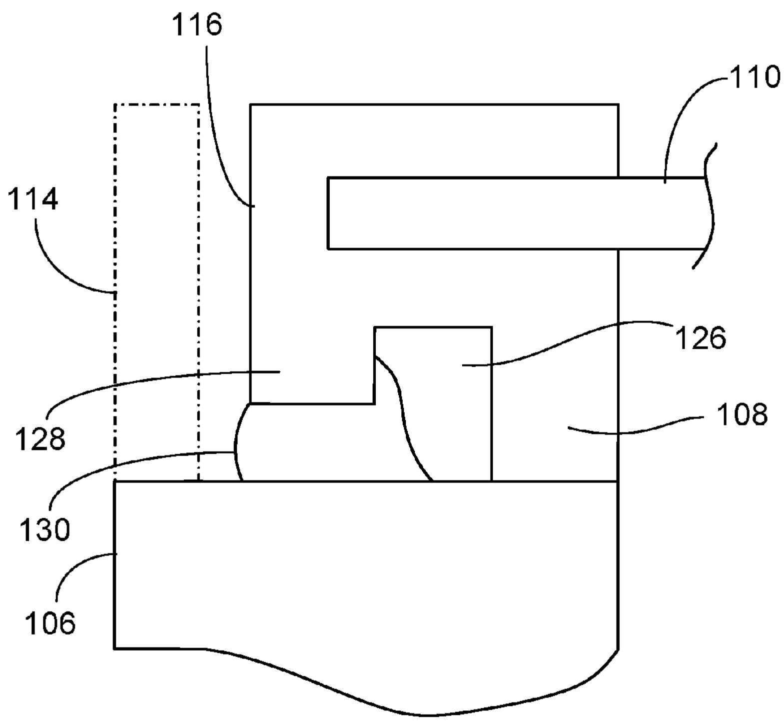
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FIG. 6B

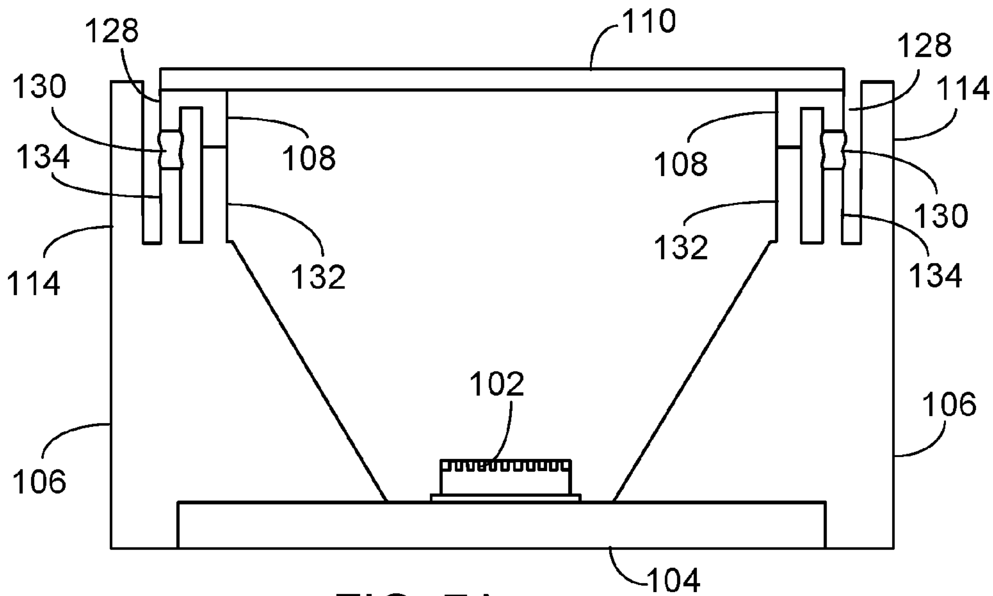
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FIG. 7A

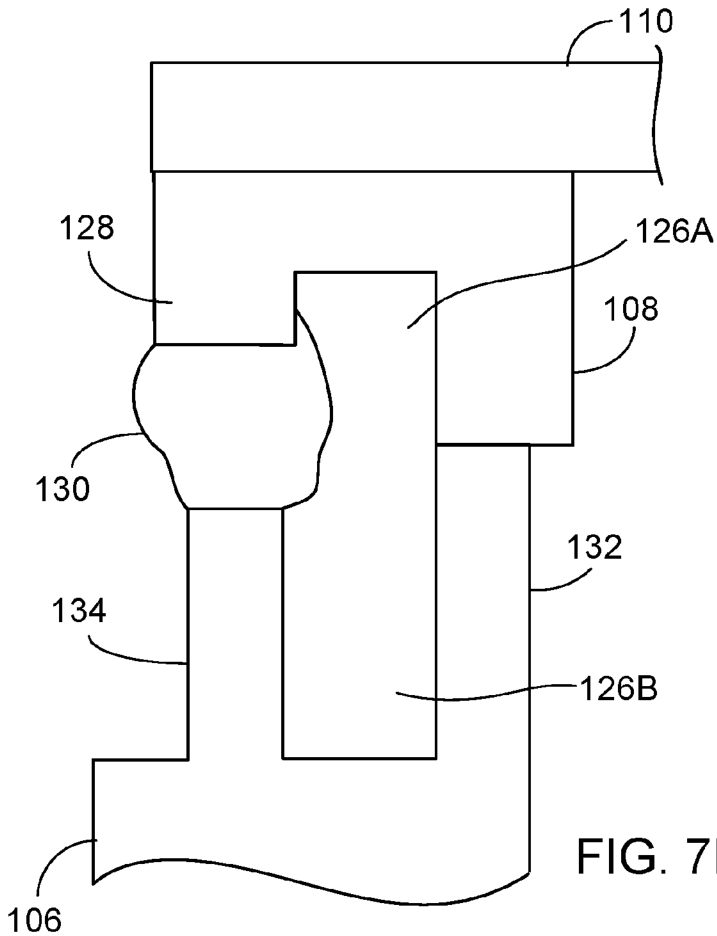
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FIG. 7B

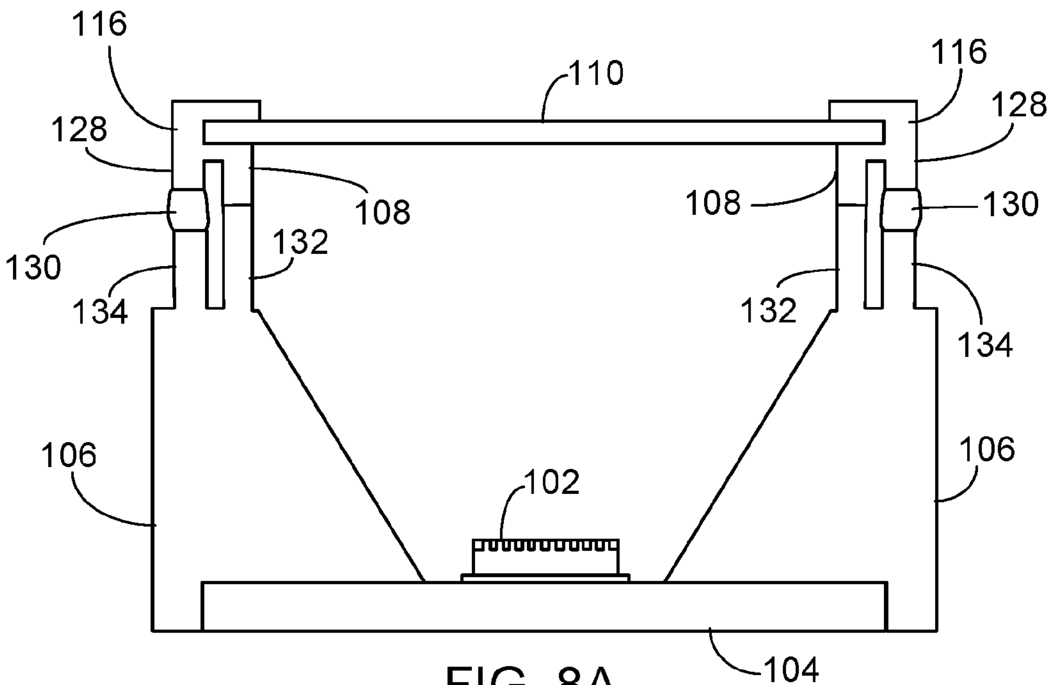
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FIG. 8A

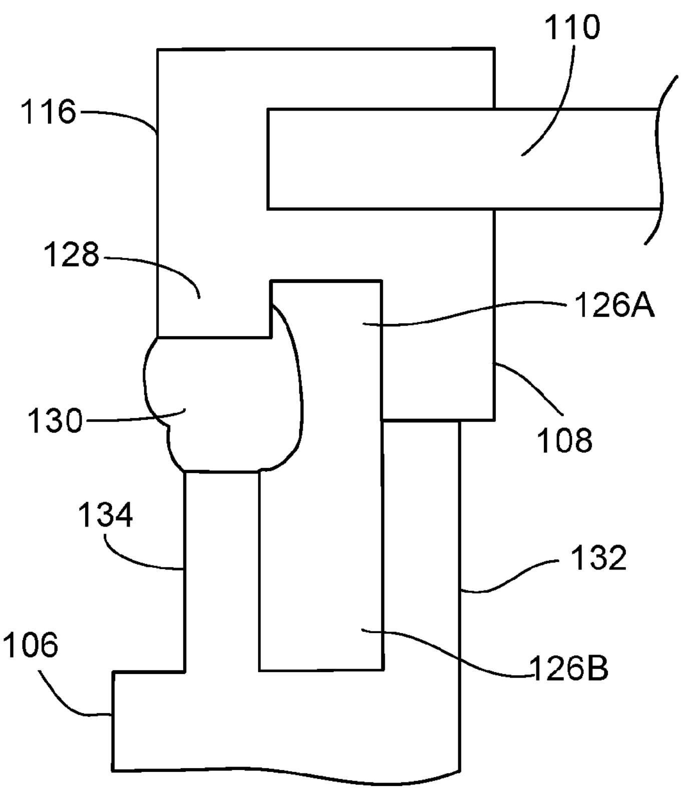
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FIG. 8B

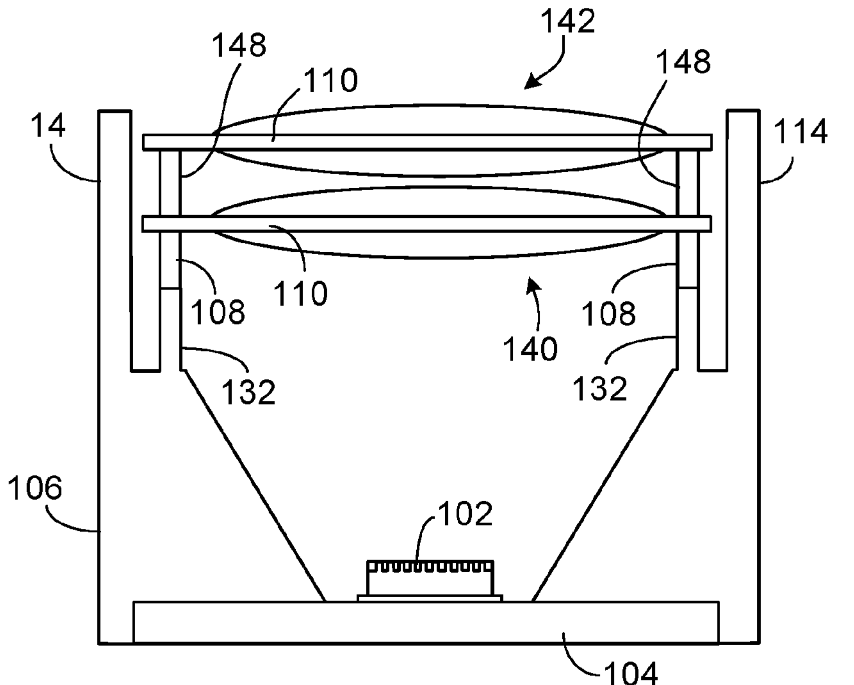
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FIG. 9A

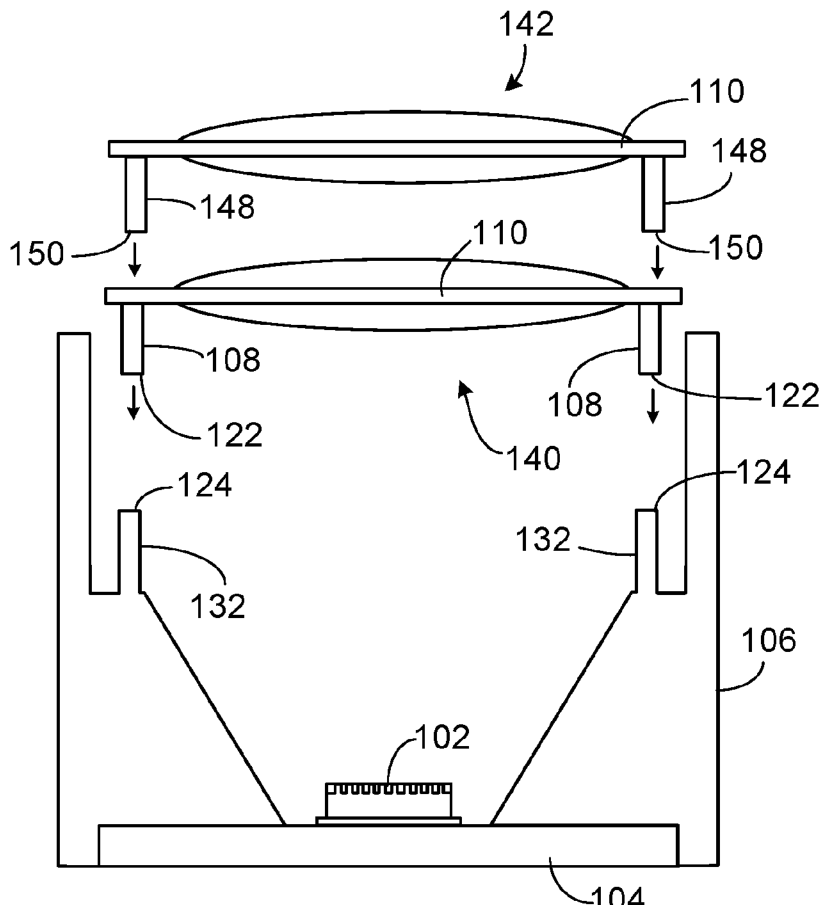
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FIG. 9B

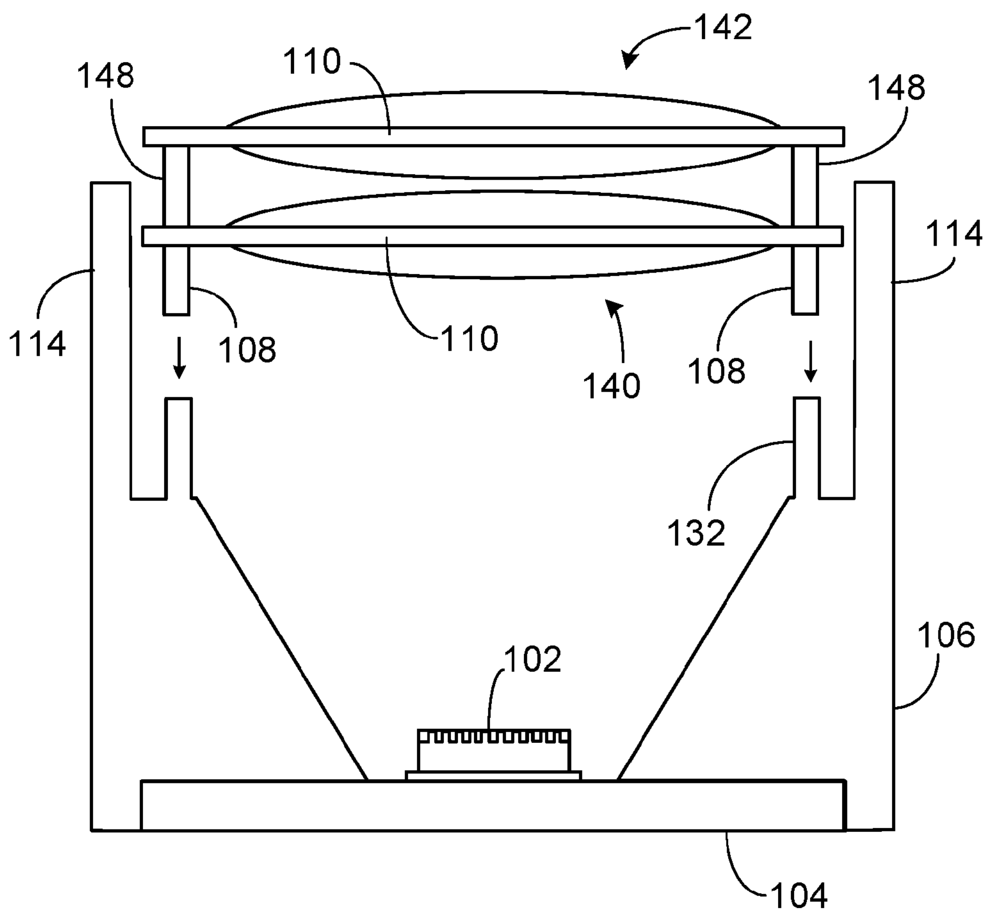

FIG. 9C

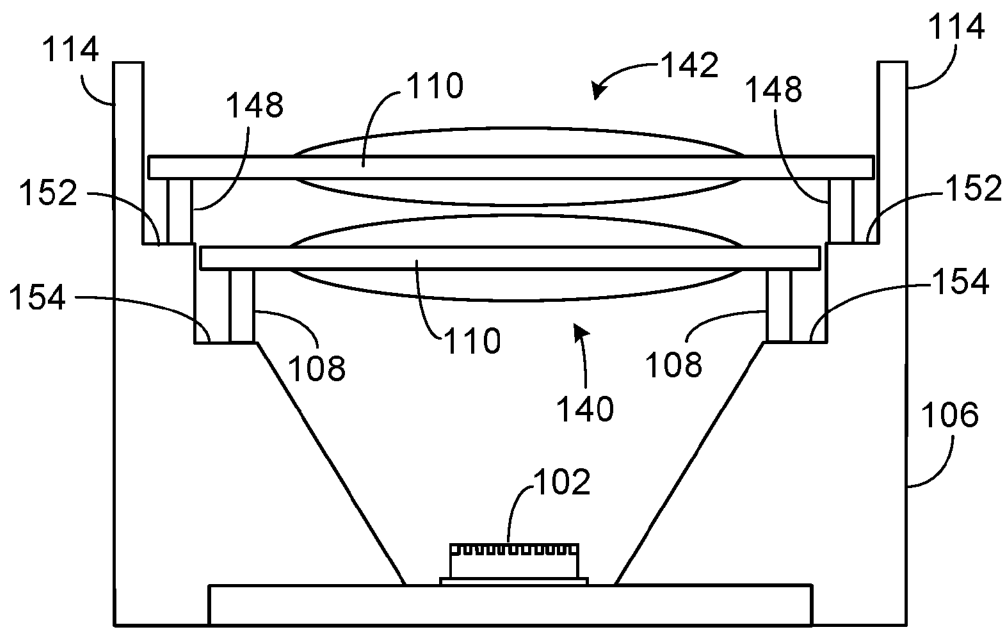

FIG. 10A

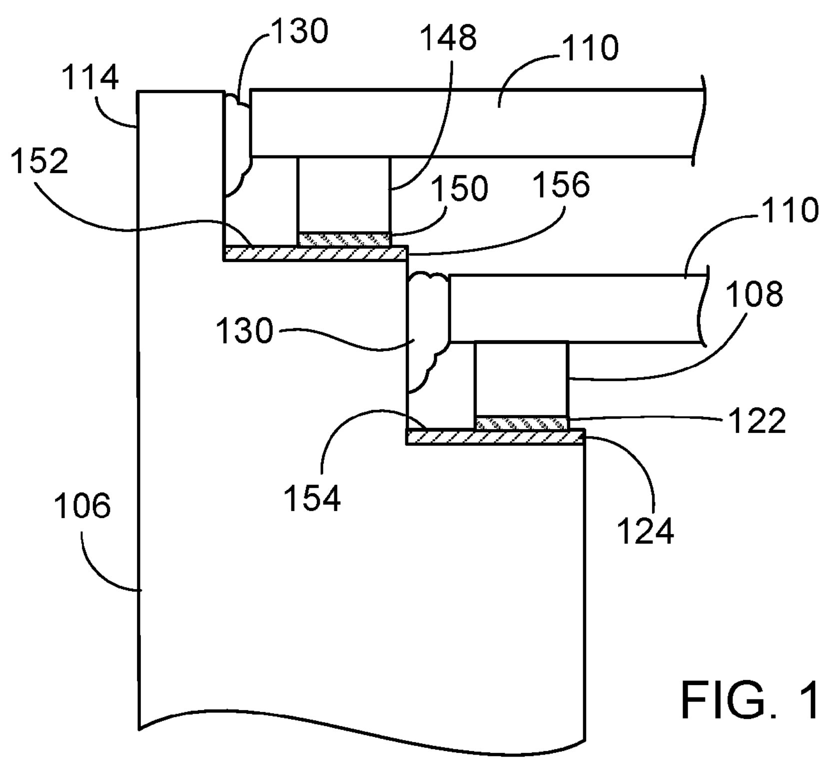

FIG. 10B

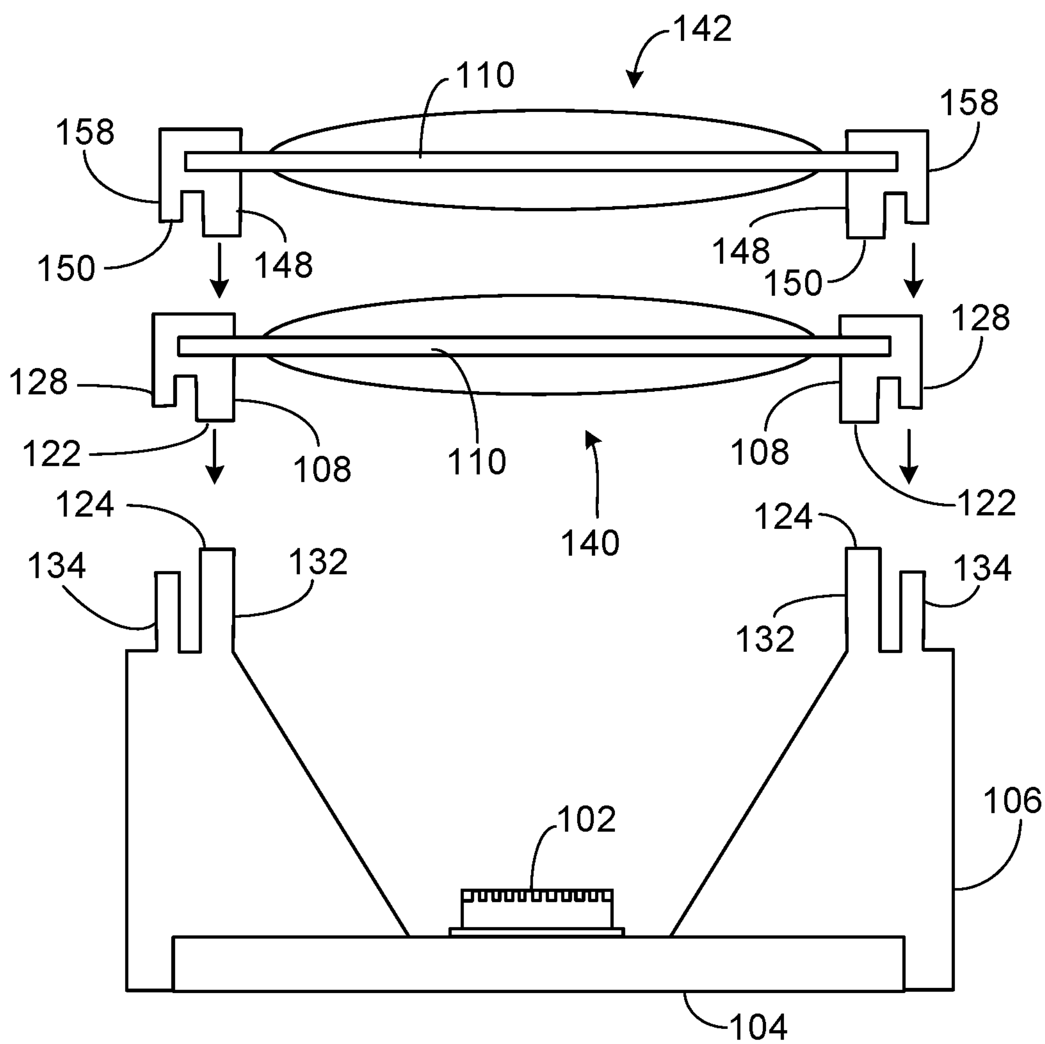
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FIG. 11

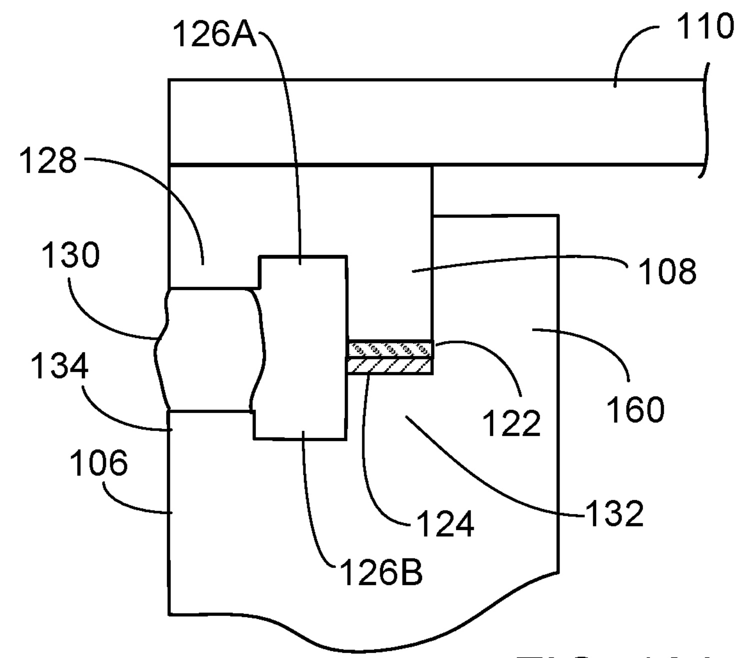

FIG. 12A

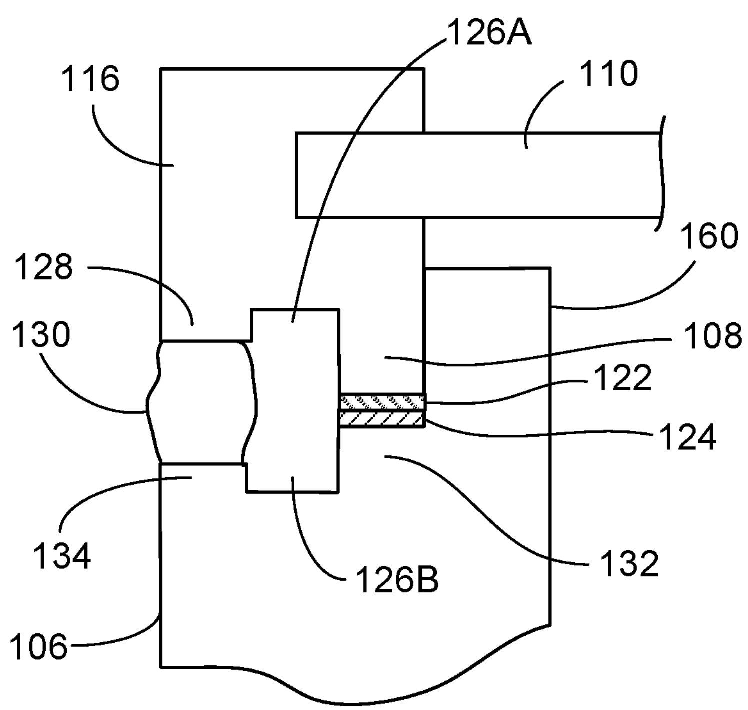

FIG. 12B

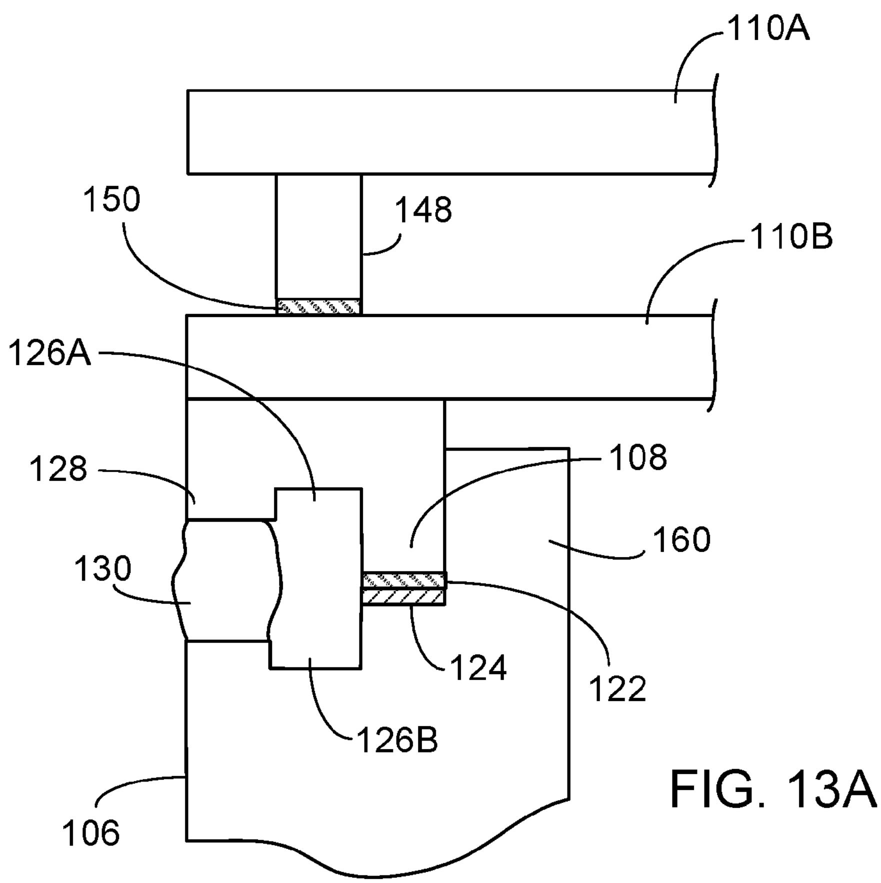

FIG. 13A

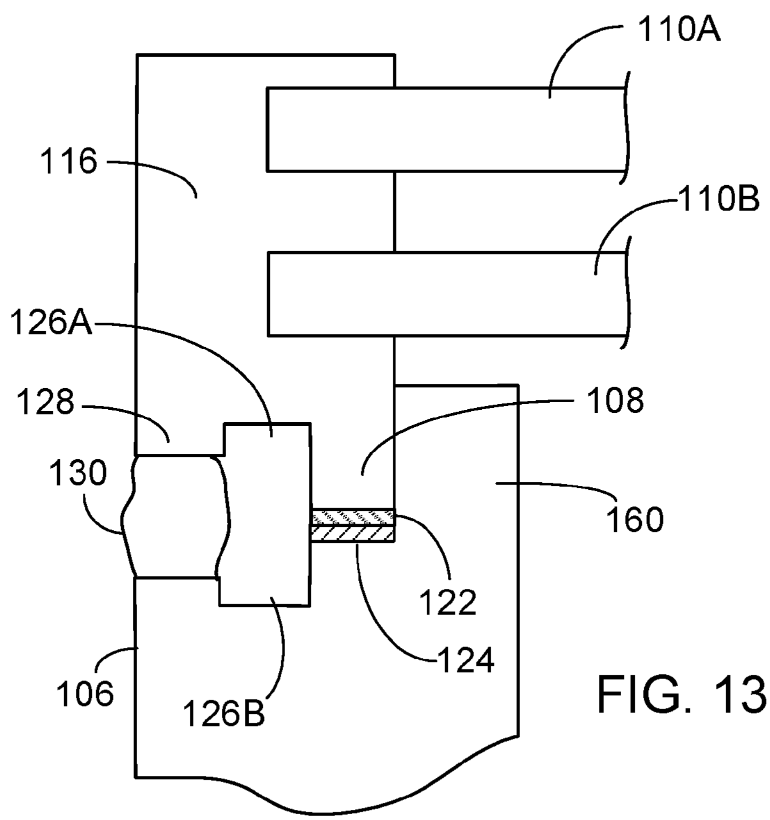

FIG. 13B

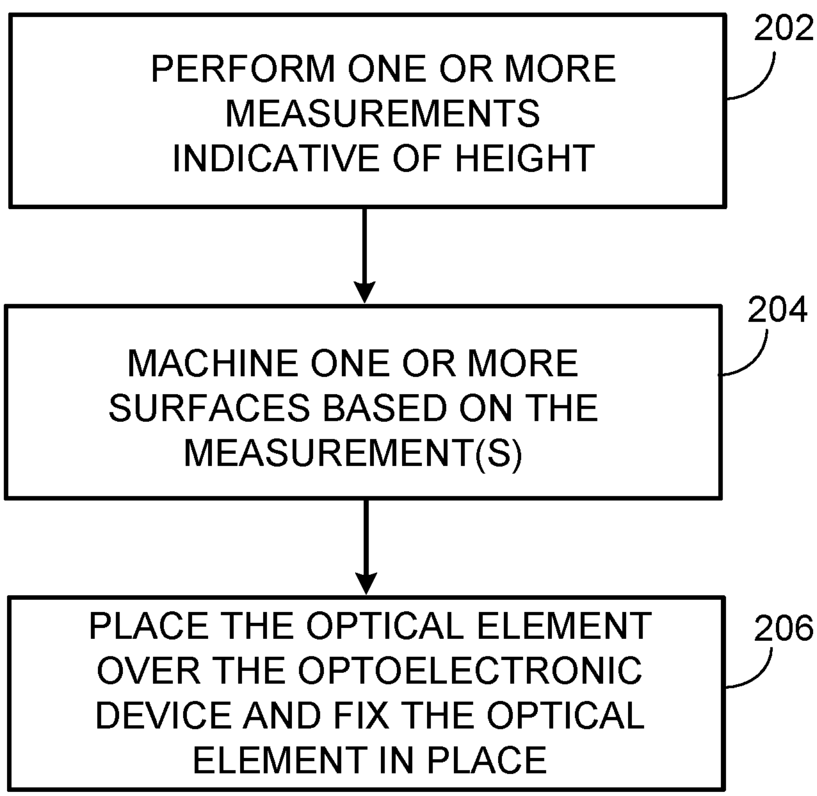
PERFORM ONE OR MORE MEASUREMENTS INDICATIVE OF HEIGHT
202
MACHINE ONE OR MORE SURFACES BASED ON THE MEASUREMENT(S)
204
PLACE THE OPTICAL ELEMENT OVER THE OPTOELECTRONIC DEVICE AND FIX THE OPTICAL ELEMENT IN PLACE
206

FIG. 14

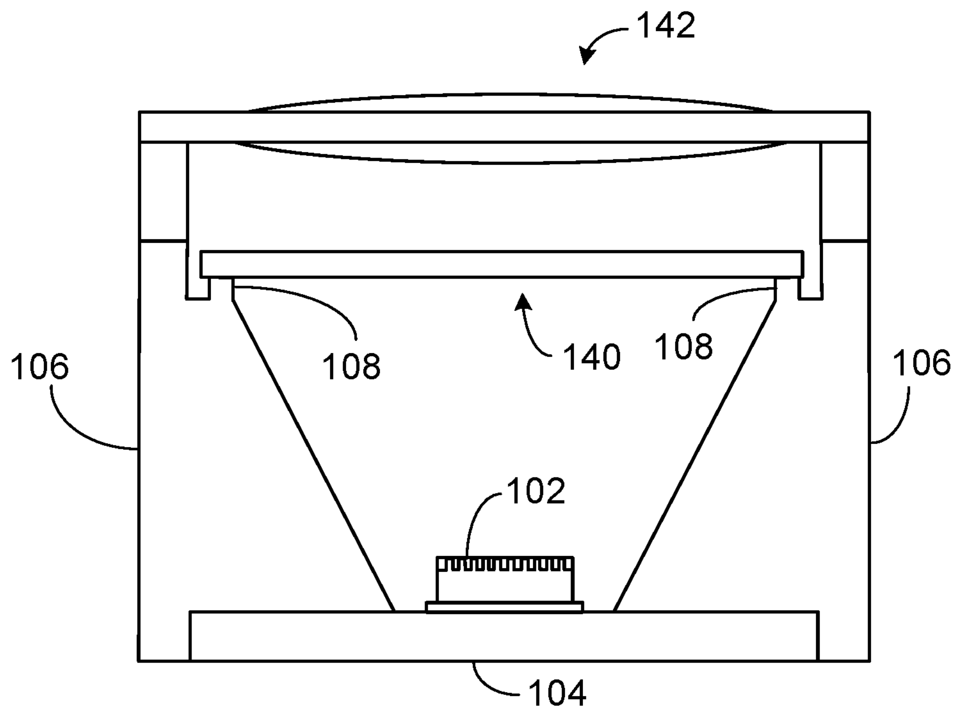
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FIG. 15

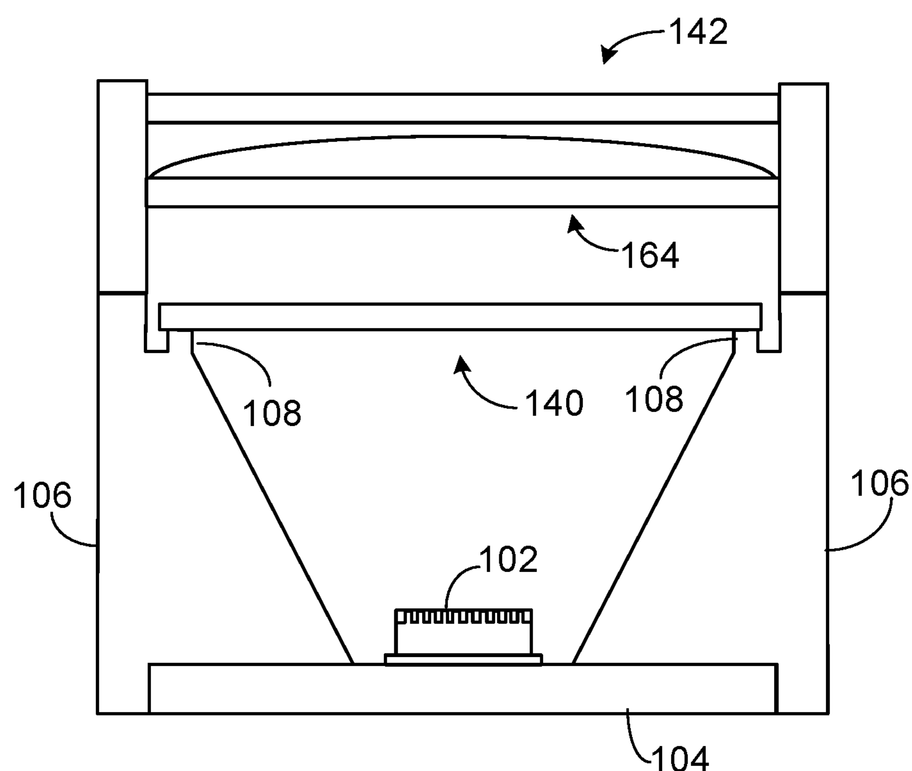
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FIG. 16

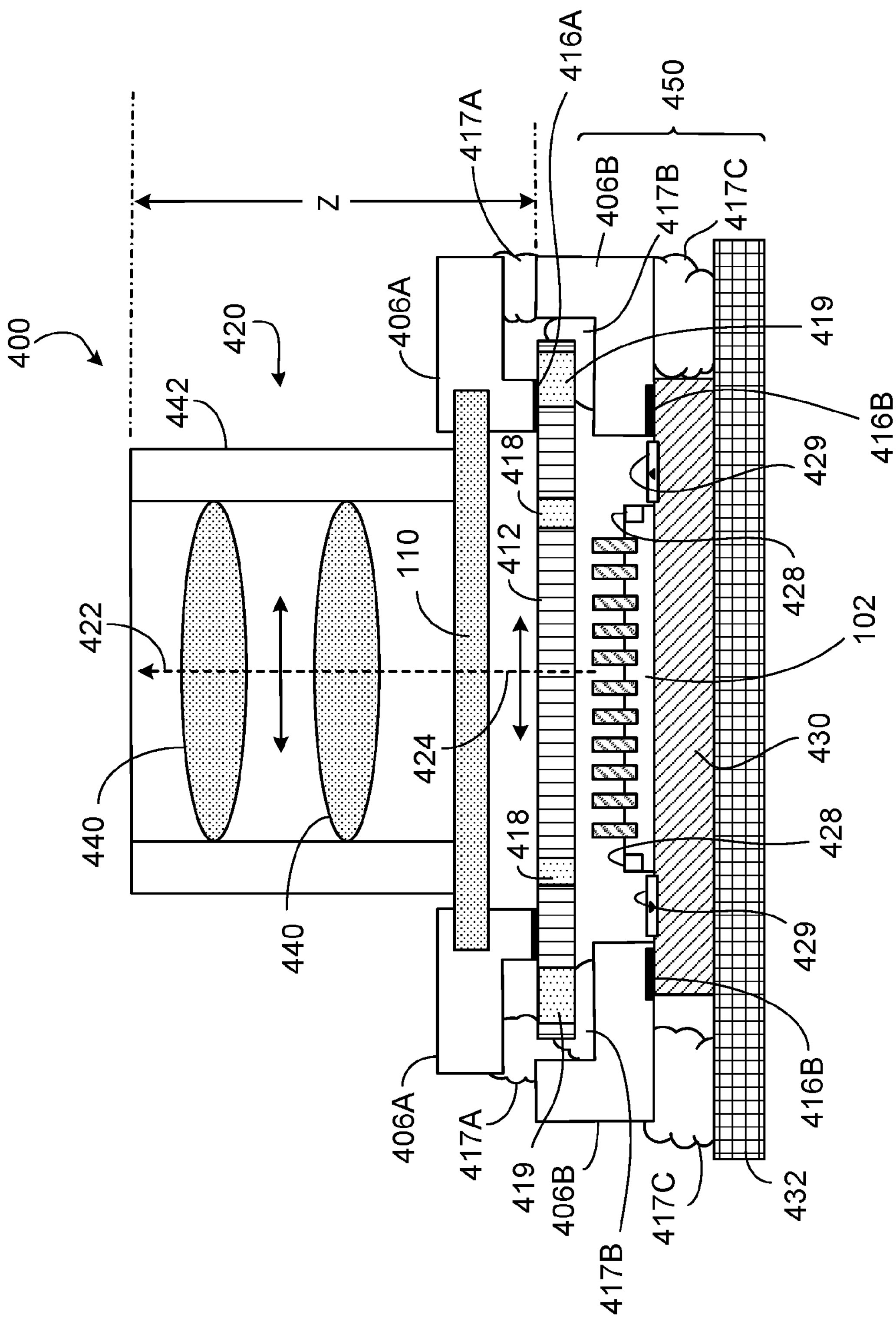
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FIG. 17

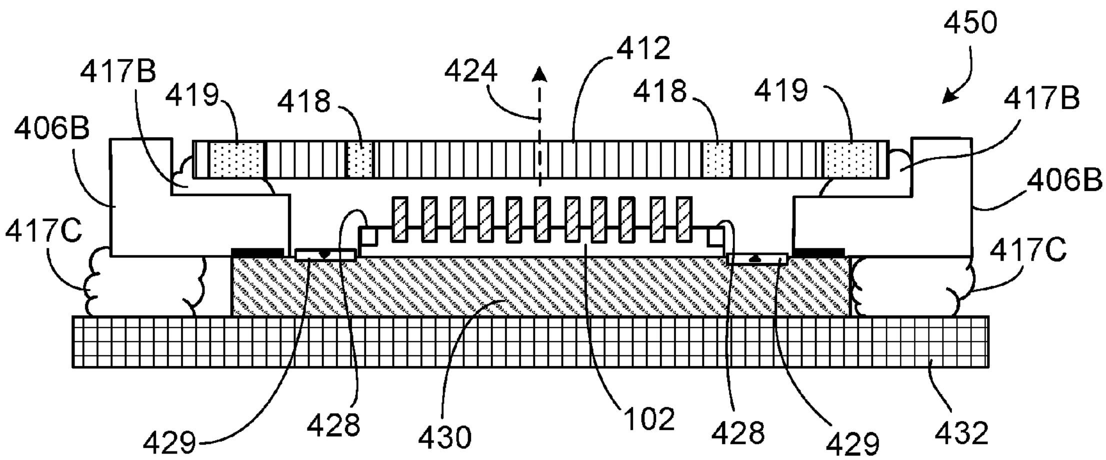

FIG. 18A

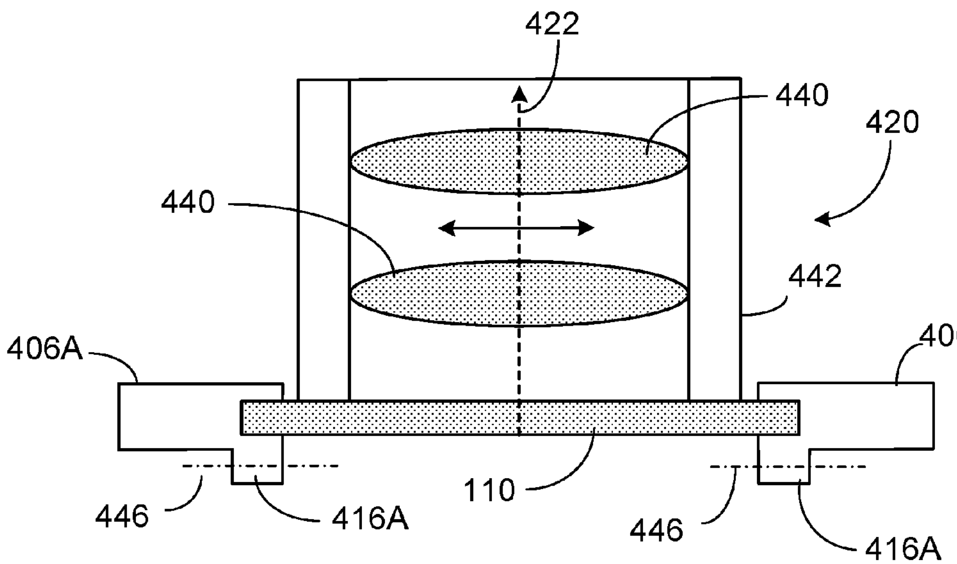

FIG. 18B

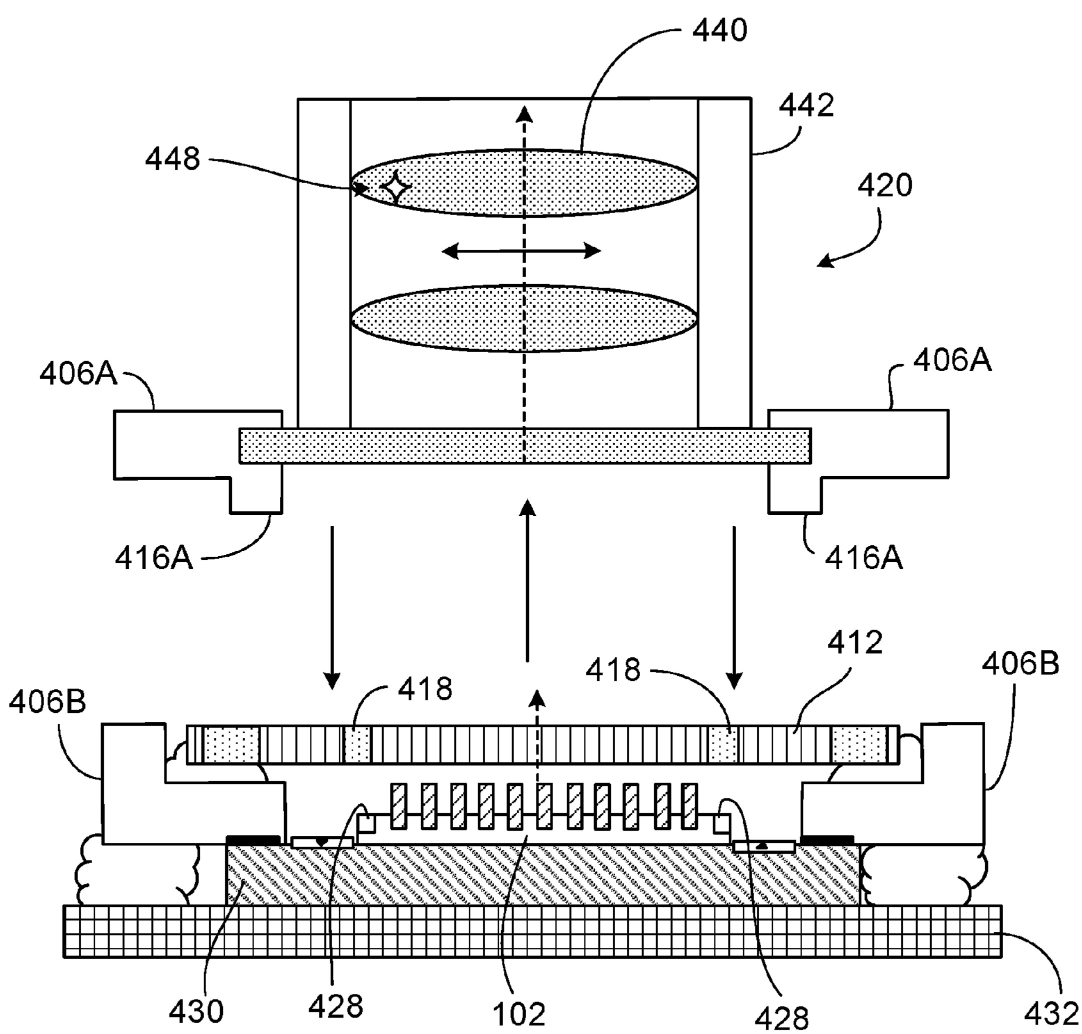
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FIG. 18C

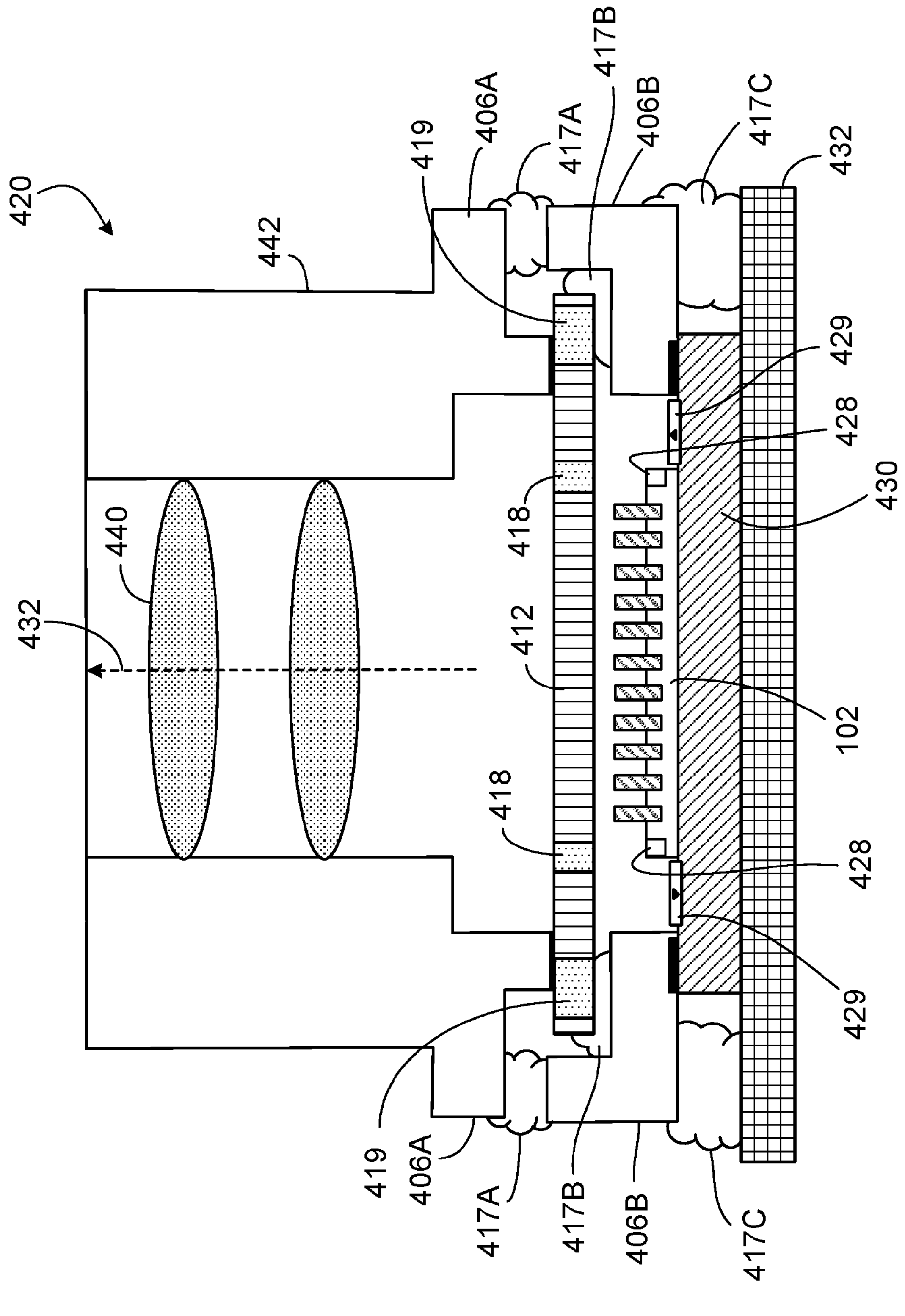
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FIG. 19

LIGHT EMITTER AND LIGHT DETECTOR MODULES INCLUDING VERTICAL ALIGNMENT FEATURES

TECHNICAL FIELD

The present disclosure relates to light emitter and light detector modules.

BACKGROUND

Various consumer electronic products and other devices include a packaged light emitter module designed for precision light projection applications. The spatial dimensions of such modules generally need to be controlled to high precision, such that the optical elements and the light emitting element are precisely positioned, for example, at an optimal distance. Thus, the modules should have very small spatial (dimensional) and optical (e.g., focal length) tolerances for optimal performance. However, the use, for example, of adhesive in the packaged light emitter module, as well as other factors such as the inherent manufacturing tolerances of the pertinent support structure, often expand the tolerances of the module to an unacceptable level. The foregoing issues may be applicable to light detector modules as well.

For some applications, the light emitter module needs to operate at optimal optical performance over a relatively large temperature range (e.g., −20° C. 70° C.), which can raise various problems. First, the spatial dimensions of the optical elements and the support structure may vary with temperature. Second, the refractive index of the optical elements may vary with temperature. This latter variation may induce a variation in focal length, causing poor performance of the light emitter module. Further, the modules often require good heat conduction.

SUMMARY

This disclosure describes various modules that can provide ultra-precise and stable packaging for a light emitting or light detecting optoelectronic device. The modules include vertical alignment features that can be machined, if needed, during fabrication of the modules, to establish a precise distance between the optoelectronic device and an optical element or optical assembly. Other features are described that, in some cases, can help facilitate improved focusing of an optical beam, for example, even over a relatively wide range of temperatures.

In one aspect, for example, a method of fabricating a light emitter or light detector module is described. The method includes providing a housing laterally surrounding an optoelectronic device mounted on a substrate and fixing a first optical element in place over the optoelectronic device using an adhesive. The optoelectronic device can be implemented, for example, as a light emitter or light detector. The optical element is substantially transparent to light emitted or detectable by the optoelectronic device. One or more vertical alignment features separate the optical element from a surface of the housing. The adhesive, however, is not provided at any interface with the vertical alignment feature(s). The method can include performance of several steps prior to fixing the optical element in place over the optoelectronic device. In particular, prior to fixing the optical element in place over the optoelectronic device, one or more measurements can be made that are indicative of a height in a direction of the module's optical axis. Further, at least one surface can be machined, by an amount based on the measurement(s), to achieve a specified distance between the optoelectronic device and the optical element. The machined surface(s) can include at least one of: (i) a contact surface of a particular vertical alignment feature, or (ii) an opposing contact surface, which comes into direct contact with the contact surface of the particular vertical alignment surface when the optical element is fixed in place over the optoelectronic device.

Various arrangements of light emitter and light detector modules that include customized (e.g., machined) vertical alignment features are described as well. For example, a light emitter module or light detector module can include an optoelectronic device mounted on a substrate, the optoelectronic device being operable to emit light or detect light. A housing laterally surrounds the optoelectronic device and serves as sidewalls for the module. An optical element is disposed over the optoelectronic device and is substantially transparent to light emitted or detectable by the optoelectronic device. One or more vertical alignment features separate the optical element from the housing, wherein the optical element is in direct contact with the one or more vertical alignment features.

Various implementations provide one or more of the following advantages. For example, the modules in some cases can provide a precise z-height such that the gap between the optoelectronic device and the optical element is within a few microns of the desired optimal value (e.g., ±5 μm and, in some cases within ±3 μm). In particular, customizable vertical alignment features can be machined during the fabrication process to achieve the desired z-height. Various approaches are described that can help avoid potentially adverse consequences of adhesive on the z-height. Other features, such as incorporating at least one optical element composed of glass and/or an auto-focus mechanism, can further help correct for offsets in the z-height. Additional features (e.g., mounting the optoelectronic device on a copper alloy substrate) also can help ensure that the module functions well over a wide range of temperatures. The techniques and modules described in this disclosure can, therefore, facilitate achieving and maintaining improved focusing of an optical beam.

In accordance with another aspect, an illumination projector module to project a light pattern includes a first assembly including an optoelectronic device operable to emit light and an optical element including a mask. The optoelectronic device is arranged to transmit light through the optical element. The module also includes an optical assembly including one or more optical elements and a first spacer having one or more vertical alignment features that are in direct contact with the optical element that includes the mask. The first spacer also is fixed to a second spacer that forms part of the first assembly and that laterally surrounds the optoelectronic device.

One or more of the following features are included in some implementations. For example, the first spacer can be fixed to the second spacer by adhesive. The optical element that includes the mask can have one or more transparent windows each of which is aligned with a respective alignment mark on the optoelectronic device. Such windows can help facilitate alignment of the optical assembly with the optoelectronic device. The optical element that includes the mask can be fixed to the second spacer by adhesive and can include one or more UV-transparent windows, each of which is disposed over at least part of the adhesive that fixes the first spacer to the second spacer. The UV-transparent windows can facilitate UV-curing of the adhesive during assem-

bly of the module. In some cases, the mask comprises a black chrome mask on a transparent substrate.

Other aspects, features and advantages will be apparent from the following detailed description, the accompanying drawings, and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**A-**1**C are cross-sections of packaged light emitter modules.

FIG. **2** is a top view of a module including discrete vertical alignment features to set the z-height between the light emitter and the cover.

FIGS. **3**A and **3**B illustrate examples of fabricating modules with one or more vertical alignment features.

FIGS. **4**A-**4**C are enlarged, partial depictions of surfaces that can be machined to obtain a desired z-height.

FIG. **5**A illustrates a cross-sectional view of another light emitter module; FIG. **5**B is an enlarged partial view of FIG. **5**A.

FIG. **6**A illustrates a cross-sectional view of yet another light emitter module; FIG. **6**B is an enlarged partial view of FIG. **6**B.

FIG. **7**A illustrates a cross-sectional view of another light emitter module; FIG. **7**B is an enlarged partial view of FIG. **7**A.

FIG. **8**A illustrates a cross-sectional view of yet another light emitter module; FIG. **8**B is an enlarged partial view of FIG. **8**A.

FIG. **9**A illustrates a cross-sectional view of a light emitter module that includes a stack of optical assemblies; FIGS. **9**B and **9**C are exploded views of FIG. **9**A.

FIG. **10**A is a cross-sectional view of another light emitter module that includes a stack of optical assemblies; FIG. **10**B is an enlarged partial view of FIG. **10**A.

FIG. **11** shows a further example of a light emitter module that includes a stack of optical assemblies.

FIGS. **12**A and **12**B are enlarged, partial views of modules that include vertical and lateral alignment features.

FIGS. **13**A and **13**B are enlarged, partial views of other modules that include vertical and lateral alignment features.

FIG. **14** is a flow chart including steps for fabricating a light emitter module.

FIG. **15** illustrates an example of a module including at least one optical member composed of glass.

FIG. **16** illustrates an example of a module including an auto-focus assembly.

FIG. **17** illustrates an example of an illumination projector.

FIGS. **18**A, **18**B, **18**C illustrate an example of assembling the illumination projector of FIG. **17**.

FIG. **19** illustrates another implementation of an illumination projector.

DETAILED DESCRIPTION

As illustrated in FIG. **1**A, a packaged light emitter module **100** can provide ultra-precise and stable packaging for a light emitter **102** mounted on a substrate **104** such as a lead frame. The light emitter **102** may be of the type that generates coherent, directional, spectrally defined light emission (e.g., a vertical cavity surface emitting laser (VCSEL) or a laser diode). In some implementations, the light emitter **102** is operable to emit infra-red (IR) light or light in the visible range of the spectrum. As the operational temperature of the light emitter **102** may be relatively high, the lead frame or other substrate **104** can be composed of a material such as a copper alloy exhibiting low thermal expansion. Such materials have relatively high thermal conductivity and, therefore, also can help provide good thermal management for the module. For example, a substrate comprised primarily of copper (whose thermal conductivity is about 260 W/(mK)) can facilitate heat being conducted away from the module rapidly, thereby preventing dimensional changes due to thermal expansion.

A housing **106** that laterally surrounds the light emitter **102** and the lead frame **104** serves as the module's sidewalls. Preferably, the housing **106** also is composed of a material exhibiting low thermal expansion (e.g., injection molded epoxy with a ceramic filler or injection molded metal). In some cases, the inner-facing surface **107** of the housing is slanted at an angle relative to the surface of the substrate **104** and defines a cone- or inverted-pyramid-shaped space **109** within which the light emitter **102** is located. A diffractive or other optical element, which may be (or which may include) a transparent cover **110**, is disposed over the light emitter **102** and is supported by one or more vertical alignment features (e.g., studs or spacers) **108** separating the main body of the housing **106** from the cover **110**. In some cases the cover **110** may be composed of glass or another transparent inorganic material such as sapphire. An advantage of using such materials is that they have a relatively low coefficient of thermal expansion compared to the lens material. To prevent or reduce light leakage from the module, the side edges **112** of the cover **110** can be shielded by non-transparent walls **114** that laterally surround the cover **110**. The walls **114** can be formed, for example, by injection molding and can be formed as a unitary piece with (and can be composed of the same material as) the body of the housing **106**.

In some cases, as shown in FIG. **1**B, the side edges **112** of the cover **110** are embedded within non-transparent encapsulant **116**. The walls **114** or encapsulant **116** can be composed, for example, of the same material as the housing **106**. In some cases, as illustrated in FIG. **1**C, one or more beam shaping elements such as lenses **118** are provided on one or both surfaces of the cover **110**. The beam shaping elements **118** and transparent cover **110** together constitute an optical assembly. In some instances, the side walls **114** that laterally surround the cover **110** extend beyond the outer surface of the cover **110** and serve as a baffle.

In some implementations, a single vertical alignment feature **108** is provided near the entirety of the cover's edge(s). In other instances, multiple (e.g., three) discrete vertical alignment features **108** can be provided (see FIG. **2**). In any event, one function of the vertical alignment feature(s) **108** is to provide a precisely defined gap between the cover **110** and the light emitter **102**.

During fabrication of the module, the vertical alignment features **108** can be machined, as needed, so as to adjust their height and thus achieve a precise pre-specified distance between the cover **110** and the light emitter **102**. For example, in some cases, the vertical alignment feature(s) **108** are formed, by injection molding and are formed as a unitary piece with (and are composed of the same material as) the housing **106** (see FIG. **3**A). Various measurements can be performed during fabrication of the modules to determine whether, and by how much, the vertical alignment feature(s) **108** should be machined. In some instances, the amount of machining may vary from one vertical alignment feature **108** to the next to correct, for example, for tilt. After machining the vertical alignment feature(s) **108**, as needed, to the desired height, the cover **110** can be placed in direct contact over the vertical alignment feature(s) **108**. To provide accurate spacing between the cover **110** and the light emitter **102**, the cover **110** is not attached to the vertical alignment feature(s) **108** by adhesive. Instead, adhesive can be provided, for example, in areas **120** between the side edges of the cover **110** and the housing **106** and/or side walls **114** (see FIG. **1**C). An example of a suitable adhesive in this and other implementations is a UV-curable epoxy.

In some instances, the vertical alignment feature(s) **108** initially are provided (e.g., by replication) on the emitter-side of the cover **110** and then machined, as needed, to the desire height, before placing them in direct contact over the housing (see FIG. **3**B). An advantage of this technique is that the vertical alignment feature(s) **108** can be machined separately from the housing **106**, thereby avoiding possible contamination of the light emitter **102**.

In some cases, in addition to, or instead of, machining the surface of the vertical alignment feature(s) **108**, the surface of the housing **106** can be machined. FIGS. **4**A-**4**C are enlarged, partial views that illustrate examples of the surface(s) **122**, **124** that can be machined to achieve a specified z-height (i.e., distance between the light emitter **102** and the optical element **110**). The surface **122** is a contact surface of the vertical alignment feature **108**, whereas the surface **124** is an opposing contact surface. These figures also illustrate an example of the location of the adhesive **130** for fixing the cover **110** in place over the housing **106** (i.e., at side edges of the cover **110**).

In some instances, an adhesive channel **126** is provided adjacent each vertical alignment feature **108**, as shown in FIGS. **5**A and **5**B. The adhesive channel **126** can be located between the vertical alignment feature **108** and an extension **128** that projects downward from the emitter-side surface of the cover **110** and that is slightly shorter than the vertical alignment feature **108**. The extension **128** can be formed, for example, by injection molding as a unitary piece with, and composed of the same material as, the vertical alignment feature **108**. During fabrication, when the cover **110** is placed over the housing, the emitter-side surface of the vertical alignment feature **108** is placed in direct contact with the surface of the housing **106** so as to establish the desired height between the light emitter **102** and the cover **110**. Adhesive **130** between the emitter-side surface of the extension **128** and the surface of the housing **106** fixes the cover **110** in place.

Preferably, the shape and dimensions of the channel **126** help prevent adhesive **130** from getting between the vertical alignment feature **108** and the underlying surface of the housing **106**. In particular, capillary forces and the wettability of the adhesive to the material of the vertical alignment features can help keep the adhesive away from the vertical alignment feature(s). The contact angle between the adhesive and the vertical alignment feature, and the channel dimensions, can be designed with this goal in mind.

In some implementations, as shown in FIGS. **6**A and **6**B, the extension **128** adjacent the adhesive channel **126** also can be formed as a unitary piece with (and composed of the same material as) the encapsulation material **116** that laterally surrounds the side edges of the cover **110**. As in the other implementations, the height of the vertical alignment feature(s) **108** can be customized, as needed, by machining to reduce their height. In the resulting module, each vertical alignment feature **108** rests directly on the housing **106** (i.e., without adhesive at the interface between the alignment feature and housing) so as to provide the desired height between the light emitter **102** and the cover **110**. As the material **116** that encapsulates the side edges of the cover **110** helps prevent light leakage from the module, the baffle walls **114** can be omitted in some instances. Nevertheless, in some cases, it still may be helpful to provide the baffle walls **114**, which can facilitate lateral alignment of the cover **110** and vertical alignment feature(s) **108**.

As illustrated in FIGS. **7**A and **7**B, some implementations include second vertical alignment feature(s) **132** and second extension(s) **134**, each of which projects from the upper surface of the housing **106**. Each second vertical alignment feature **132** is aligned with a corresponding vertical alignment feature **108** that projects from the cover **110**. The surfaces of one or both upper and lower vertical alignment features **108**, **132** can be machined, as needed, to the desired height before they are brought into direct (mechanical) contact with one another such their respective opposing surfaces abut one another. Further, each second extension **134** is aligned with a corresponding extension **128**. However, the extensions **128**, **134** are not brought directly into contact with one another. Instead, the extensions **128**, **134** serve, respectively, as upper and lower attachment features that are attached to one another by adhesive **130** to fix the cover **110** in place over the housing **106**. Upper and lower adhesive channels **126**A, **126**B can help prevent the adhesive **130** from flowing too close to the vertical alignment features **108**, **132**. Thus, the combined heights of the upper and lower vertical alignment features **108**, **132** help achieve a precise specified distance between the light emitter **102** and the cover **110**, whereas the extensions **128**, **134** and the adhesive **130** fix the cover **110** to the housing **110**.

FIGS. **8**A and **8**B illustrate an example of another module that includes second vertical alignment feature(s) **132** and second extension(s) **134**, each of which projects from the upper surface of the housing **106**. Thus, like the module in FIGS. **7**A and **7**B, the module in FIGS. **8**A and **8**B includes both upper and lower vertical alignment features. Further, the side edges of the cover **110** of the module in FIGS. **8**A and **8**B are encapsulated laterally by opaque material **116** that can be formed as a unitary piece with (and composed of the same material as) the vertical alignment feature **108** and extension **128**. As the material **116** that encapsulates the side edges of the cover **110** helps prevent light leakage from the module, the baffle walls **114** may be omitted in some instances.

Customizable vertical alignment features also can be used to stack multiple optical assemblies one over the other. An example is illustrated in FIG. **9**A, which shows a module that includes a stack of first and second optical assemblies **140**, **142**. The optical assemblies **140**, **142** may be separated from one another by one or more customizable vertical alignment feature(s) **148** that are on the emitter-side surface of the transparent plate **110** of the upper assembly **142**. The emitter-side surface of the vertical alignment feature(s) **148** rests directly (i.e., without adhesive) on the upper surface of the transparent plate **110** of the lower assembly **140**. As shown in FIG. **9**B, in some implementations, the lower optical assembly **140** is placed on vertical alignment feature(s) **132** extending from the housing **106**, and subsequently the upper assembly **142** is placed on the lower assembly **140**. The optical assemblies **140**, **142** can be fixed in place, for example, by using adhesive between the side edges of the optical elements **110** and the upper sidewalls **114** of the module, as illustrated in FIG. **4**A. Prior to placing the optical assemblies **140**, **142** over the housing **106**, one or more of the vertical alignment surfaces **122**, **124**, **150** can be machined so that the distance from the light emitter **102** is in accordance with a specified value. In some implementations, as shown in FIG. **9**C, the optical assemblies **140**, **142** can be stacked one on the other, and then the entire stack can be placed on the vertical alignment feature(s) **132**.

In some cases, as shown in FIG. **10**A, the vertical alignment features **148** of the upper optical assembly **142** can rest directly on an upper ledge **152** of the housing **106**, just as the vertical alignment features **108** of the lower optical assembly **140** rest on a lower ledge **154**. As illustrated in FIG. **10**B, one or more surfaces **122**, **124**, **150**, **156** of the vertical alignment features **108**, **148** or ledges **152**, **154** can be machined, as needed, prior to positioning the optical assemblies **140**, **142** so as to provide the desired relative distance between the light emitter **102** and each optical assembly. The optical assemblies **140**, **142** can be fixed in place, for example, by adhesive **130** between their side edges and the inner-facing surface(s) of the housing **106**.

As illustrated in FIG. **11**, a stack of optical assemblies **140**, **142** also can be placed on the housing using some of the features described in connection with FIGS. **7**A and **8**A (i.e., an adhesive channel formed between the vertical alignment feature **108**/**148** and a corresponding extension **128**/**158** projecting from the emitter-side of the transparent plate **110**). Also, in some cases, the side edges of the optical elements **110** can be encapsulated by opaque material, as described above in connection with FIG. **8**A. One or more of the contact surfaces **122**, **124**, **150** of the vertical alignment features **108**, **132**, **148** can be machined, as needed, prior to positioning the optical assemblies **140**, **142** so as to achieve the desired distance between the light emitter **102** and each optical assembly. As in the previously described examples, there is no adhesive at the contact surfaces **122**, **124**, **150**, which allows the distance to the emitter **102** to be established precisely. Instead, the adhesive can be provided at the surfaces of the extensions **134**, **128**, **158**.

In addition to the vertical alignment features (e.g., **108**, **132**), some implementations include lateral alignment features **160**, as illustrated, for example, in FIGS. **12**A and **12**B. The lateral alignment feature **160** can be formed, for example, as a unitary piece with (and can be composed of the same material as) the lower vertical alignment feature **132** and the housing **106**. In particular, the lateral alignment feature **160** can take the form of an extension that projects from the housing next to the lower vertical alignment feature **132**. The lateral alignment feature(s) **160** can facilitate placement of the upper vertical alignment feature(s) **108** onto the lower vertical alignment features(s) **132**. In the resulting module, a side of each lateral alignment feature **160** is in direct contact with a side of a corresponding upper vertical alignment feature **108**. Further, the lateral alignment feature(s) **160** can help protect the light emitter **102** from small particles resulting from machining of the surfaces **122**, **124**. In some cases, a stack of optical assemblies can be provided. As shown in FIG. **13**A, the upper optical element **110**A can be separated from the lower optical element **110**B by a vertical alignment feature (i.e., a stud or spacer) **148**. The contact surface **150** of the vertical alignment feature **148** can be machined prior to bringing it into contact with the lower optical element **110**B so as to achieve a desired distance between the light emitter **102** and the upper optical element **110**A. In other instances, as illustrated in FIG. **13**B, the side edges of both covers **110**A, **110**B can be encapsulated laterally by opaque material **116**. Here too, the encapsulation material **116** can be formed as a unitary piece with (and composed of the same material) as the vertical alignment feature **108** and the extension **128**. In some cases, the lateral alignment feature **160** may be omitted.

As is apparent from the foregoing detailed description, contact surfaces of the vertical alignment features, or of the ledge(s) and other surfaces on which they rest, can be machined to achieve a precisely defined distance between the light emitter and an optical element in the module. The extent of any machining that may be needed can be based, for example, on various measurements made during the fabrication process. The entire process may, in some cases, be automated.

In the foregoing implementations, the vertical alignment features (e.g., **108**, **132**, **148**) can be implemented, for example, either as a single contiguous spacer or as multiple discrete studs/spacers (see FIG. **2**).

As indicated by the various examples described above, during fabrication of the modules, one or more measurements can be made prior to fixing an optical element (e.g., cover **110** or optical assembly **140**, **142**) in place over the light emitter **102** (see FIG. **14**, block **202**). The measurements can be indicative of a height in the direction of the module's optical axis (i.e., parallel to arrow **111** in FIG. **1**). For example, the measurement(s) may include focal-length measurements of the optical element, and/or the height of the housing and/or vertical alignment features may be measured optically prior to or during machining. Based on the optical measurement(s), one or more surfaces can be machined, as necessary, to establish precisely a specified distance between the light emitter and the optical element (block **204**). The machined surfaces may include a contact surface of a vertical alignment feature and/or an opposing contact surface for the vertical alignment feature (i.e., a surface that abuts the contact surface of the vertical alignment feature when the optical element is fixed in place over the light emitter). Although the surface that abuts the contact surface of the vertical alignment feature when the optical element is fixed in place over the light emitter may be referred to as an "opposing contact surface," that surface need not necessarily be opposite the contact surface of the vertical alignment feature when the surfaces are machined. After performing the machining (if any), the optical element is placed over the light emitter such that the one or more vertical alignment feature(s) separate the optical element from the module's housing and the optical element is fixed in place (block **206**). Adhesive is not used at any interfaces with the vertical alignment features. Instead, the optical element can be fixed to the housing by providing adhesive at other locations (e.g., along the side edges of the optical element or at a separate adhesive attachment surface. In some implementations, multiple modules can be fabricated in parallel using a wafer-level process.

In some implementations, a module including vertical alignment features as described above also can include other features to provide a precision packaged light emitter module that is relatively stable over a wide temperature range. For example, although the optical element (e.g., **110**, **140**, **142**) can be composed of a polymer material, in some implementations, to reduce thermally induced dimensional changes (e.g., changes in z-height), one or more of the optical elements can be composed of glass, which typically has a lower thermal expansion than many polymers. An example is illustrated in FIG. **15**, which shows a module that a first optical element **140** composed of a polymer material. The module also includes a second optical element **142** composed of a glass lens.

To alleviate dimensional changes caused by thermal expansion even further, some implementations include an auto-focus mechanism **164** (see FIG. **16**). The auto-focus mechanism **164** can be implemented, for example, as a tunable lens or a piezo-electric element. The auto-focus mechanism can be used alone or in conjunction with a glass optical element and/or the customizable vertical alignment features to provide very accurate and precise optical performance for the light emitter module. Other features described in the various implementations described above also can be combined in the same module.

Various electrical connections can be provided to or from the light emitter **102**. Such electrical connections may include, for example, conductive vias through the housing **106** and/or connections in the form of an electrically conductive coating on the interior or exterior surface of the housing **106**. The wiring can provide electrical connections, for example, between the emitter **102** and the substrate **104**. Electrical pads or other connections on the backside of the substrate **104** can facilitate connections to other devices or modules, which may be mounted, for example, together with the light emitter module on a printed circuit board.

In some implementations, the module can include an optical element having a mask (e.g., a black chrome mask on the transparent substrate **110**). An example of such am implementation is described in detail below.

FIG. **17** illustrates another example of an illumination projector **400**. To generate a high-quality light projection/illumination, precise alignment preferably should be provided as follows: (1) the focal length of the optical assembly **420** should fall on the plane of the mask **412**, and (2) the (central) optical axis **422** of the assembly **420** should coincide with the (central) optical axis **424** of the emitter (e.g., VCSEL **102**). As discussed above, the thickness of adhesive layers cannot be controlled precisely. Accordingly, the optical assembly **420** is provided with a first spacer **406**A having vertical alignment features **416**A that allow a height Z (i.e., a distance between the mask **412** and the optical assembly) to be precisely defined via a direct mechanical connection. Further, the optical assembly **420** can be fixed in place via adhesive **417**A applied between the first spacer **406**A and a second spacer **406**B that forms part of the housing for the light emitting element (e.g., VCSEL **102**). The first spacer **406**A can be formed separately from the lens barrel **442** of the optical assembly **420**, as in the example of FIG. **17**, or can be formed as a single integral piece with the lens barrel **442**, as in the example of FIG. **19**.

One challenge in aligning the optical axis **422** of the assembly **420** with the optical axis **424** of the VCSEL **102** is that during assembly, the optical element including the mask **412** is attached to the VCSEL assembly, whereas the optical assembly **420** subsequently is attached to the VCSEL/mask assembly. Thus, a problem can arise because the VCSEL **102** cannot be seen through the mask **412** for purposes of alignment. To alleviate this issue, transparent alignment windows **418** can be incorporated into the optical element that includes the mask **412** so that alignment marks **428** on the VCSEL **102** can be seen when the optical assembly **420** is attached to the VCSEL assembly **450**. The optical assembly **20** can thus be aligned precisely to the VCSEL **102**.

FIGS. **18**A, **18**B, **18**C illustrate an example process for assembling the module **400**. The VCSEL **102** is mounted on a sub-mount assembly, which can include, for example, a metal (e.g., copper) trace **430** on a sub-mount **432**. To facilitate horizontal alignment of the VCSEL **102** on the metal trace **430**, alignment features **429** can be provided on the VCSEL-side surface of the metal trace **430**.

As further shown in FIG. **18**A surface **416**B of the second spacer **406**B abuts (i.e., is in direct mechanical contact with) the VCSEL-side surface of the metal trace **430**. If desired, the surface **416**B can be machined beforehand so as to provide more precise vertical alignment. The spacer **406**B thus includes vertical alignment features (i.e., surface **416**B). The spacer **406**B also can be fixed to the sub-mount **432** by adhesive **417**C. Advantageously, in the illustrated example, the adhesive **417**C is not in close proximity to the VCSEL **102**. Further, direct mechanical contact between the spacer **406**B and the metal trace **430** can result in better height accuracy as there is no intervening layer of variable height/thickness.

As further shown in FIG. **18**A, the second spacer **406**B, which laterally surrounds the VCSEL **102**, separates the mask **412** from the VCSEL/sub-mount assembly. The optical element that includes the mask **412** can be fixed to the second spacer **406**B by adhesive **417**B, which can be cured, for example, by UV radiation. UV-transparent windows **419** in the mask **412** permit the adhesive **417**B to be cured using UV radiation. FIG. **18**A shows the resulting VCSEL assembly **450**.

As shown in FIG. **18**B, the optical assembly **420** can include one or more optical elements (e.g., lenses) **440** held by a barrel **442** over a transparent cover **110**. In the illustrated example, the first spacer **406**A laterally surrounds the transparent cover **110**. In other cases, as show in in FIG. **19**, the first spacer **406**A can be formed integrally as a single piece with the barrel **442**. In such cases, the transparent cover **110** may be omitted.

The distance between the optical assembly **420** and the mask **412** should be controlled carefully so that the focal length of the optical assembly **420** coincides with the plane of the mask **412**. Thus, in some cases, the height of the spacer **406**A can be customized, for example, by machining, as indicated by the horizontal dashed lines **446** in FIG. **18**B. Machining also can be used, if needed, to correct for tilt. In some cases, the spacer **406**A can be manufactured to sufficient accuracy such that that further dimensional customization is unnecessary. The first spacer **406**A thus includes vertical alignment features (i.e., the surface **416**A).

Next, the optical assembly **420** is attached to the VCSEL assembly **450**. The position of the (central) optical axis **422** of the optical assembly **420** is determined. Also, the position of the (central) optical axis **424** of the VCSEL **102** is determined using, for example, the alignment windows **418** and the alignment marks **428** on the surface of the VCSEL **102**. The optical assembly **420** also may include one or more alignment marks, for example, one or more alignment marks **448** on the lenses **440**. The two assemblies **420**, **450** then are fixed to one another (see FIG. **18**C), for example, with an adhesive **417**A such as epoxy (see FIG. **18**A). In particular, the first and second spacers **406**A, **406**B can be fixed to another via epoxy **417**A. The vertical alignment features of the spacer **406**A (i.e., surface **416**A) abuts (i.e., is in direct mechanical contact with) the optical assembly-side surface of the mask **412** so as to precisely define the height Z (FIG. **17**) and so as to precisely fix the distance between the optical assembly **420** and the mask **412**.

Although the foregoing examples are described in the context of modules that include a light emitter, in some implementations the module may include a different type of active optoelectronic device such as a light detector. For example, instead of the device **102** being a light emitter, it may be an image sensor that includes an array of light sensitive elements (i.e., pixels). In the context of modules that include a light detector, the various features described above can be advantageous, for example, in establishing a proper z-height such that the focal-length of a lens is on the image sensor. Other features (e.g., providing opaque encapsulant **116** surrounding the side edges of the transparent cover **110**) may be useful in preventing stray light from impinging on the image sensor.

Terms such as "transparent," "non-transparent" and "opaque" are used in this disclosure with reference to the wavelength(s) of light emitted or detectable by the optoelectronic device. Thus, in the context of the present disclosure, a material or component that is non-transparent or opaque may allow light of other wavelengths to pass through with little or no attenuation. Likewise, a material or component that is transparent to light emitted or detectable by the optoelectronic device may not allow light of other wavelengths to pass or may significantly attenuate light of such other wavelengths.

The modules described here may be integrated into a wide range of consumer products and/or other electronic devices, such as bio devices, mobile robots, surveillance cameras, camcorders, laptop computers, tablet computers, and desktop computers, among others.

Other implementations are within the scope of the claims.

What is claimed is:

1. An illumination projector module to generate a light pattern, the module comprising:
- a first assembly including:
  - an optoelectronic device operable to emit light; and
  - an optical element including a mask, wherein the optical element has one or more transparent windows each of which is aligned with a respective alignment mark on the optoelectronic device, the optoelectronic device being arranged to transmit light through the optical element;
- an optical assembly including one or more optical elements; and
- a first spacer having one or more vertical alignment features in direct contact with the optical element that includes the mask,
- the first spacer being fixed to a second spacer that forms part of the first assembly and that laterally surrounds the optoelectronic device.

2. An illumination projector module to generate a light pattern, the module comprising:
- a first assembly including:
  - an optoelectronic device operable to emit light; and
  - an optical element including a mask, the optoelectronic device being arranged to transmit light through the optical element;
- an optical assembly including one or more optical elements; and
- a first spacer having one or more vertical alignment features in direct contact with the optical element that includes the mask,
- the first spacer being fixed to a second spacer that forms part of the first assembly and that laterally surrounds the optoelectronic device,
- wherein the optical element that includes the mask is fixed to the second spacer by adhesive, the optical element that includes the mask further including one or more UV-transparent windows each of which is disposed over at least part of the adhesive that fixes the second spacer to the optical element that includes the mask.

3. An illumination projector module to generate a light pattern, the module comprising:
- a first assembly including:
  - an optoelectronic device operable to emit light; and
  - an optical element including a black chrome mask on a transparent substrate, the optoelectronic device being arranged to transmit light through the optical element;
- an optical assembly including one or more optical elements; and
- a first spacer having one or more vertical alignment features in direct contact with the optical element that includes the mask,
- the first spacer being fixed to a second spacer that forms part of the first assembly and that laterally surrounds the optoelectronic device.

4. A method of manufacturing an illumination projector module, the method comprising:
- providing a first subassembly including: an optical assembly, and a first spacer having one or more alignment features;
- providing a second subassembly including: an optical element that includes a mask, an optoelectronic device operable to emit light through the optical element, and a second spacer that laterally surrounds the optoelectronic device, wherein the optical element that includes the mask is attached to the second spacer;
- attaching the first and second subassemblies to one another such that the alignment features of the first spacer are in direct contact with a surface of the optical element that includes the mask,
- wherein providing the second subassembly includes aligning the optical element that includes the mask with respect to the optoelectronic device, wherein the aligning includes viewing one or more alignment marks on the optoelectronic device through one or more transparent windows in the optical element that includes the mask.

5. A method of manufacturing an illumination projector module, the method comprising:
- providing a first subassembly including: an optical assembly, and a first spacer having one or more alignment features;
- providing a second subassembly including: an optical element that includes a black chrome mask on a transparent substrate, an optoelectronic device operable to emit light through the optical element, and a second spacer that laterally surrounds the optoelectronic device, wherein the optical element that includes the mask is attached to the second spacer; and
- attaching the first and second subassemblies to one another such that the alignment features of the first spacer are in direct contact with a surface of the optical element that includes the mask.

6. The illumination projector module of any one of claim **1**, **2** or **3** wherein the first spacer is fixed to the second spacer by adhesive.

7. The illumination projector module any one of claim **1**, **2** or **3** wherein the optical assembly includes one or more lenses within a lens barrel, and wherein the first spacer and the lens barrel form a single unitary piece.

8. The illumination projector module any one of claim **1**, **2** or **3** wherein the first spacer establishes a distance between the mask and the optical assembly.

9. The illumination projector module any one of claim **1**, **2** or **3** wherein the second spacer establishes a distance between the mask and the optoelectronic device.

10. The method of claim **4** wherein attaching the first and second subassemblies to one another includes fixing the first and second spacers to one another by adhesive.

11. The method of claim **4** further including:
- attaching the optical element that includes the mask to the second spacer by adhesive; and

providing UV radiation through one or more windows in the optical element that includes the mask so as to cure the adhesive.

12. The method of any one of claim **4** or **11** wherein the first spacer establishes a distance between the mask and the optical assembly.

13. The method of any one of claim **4** or **11** wherein the second spacer establishes a distance between the mask and the optoelectronic device.

14. The method of any one of claim **4** or **11** further including machining the alignment features of the first spacer so that a focal length of the optical assembly coincides with a plane of the mask when the first and second assemblies are attached to one another.

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